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MRP Rs 640.00

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Published by :
PAPERGPT
125, Sector 6, Vidyadhar Nagar, Jaipur 302039
Phone :+91 9001005245

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07. PLANT BIOCHEMISTRY

Unit 1: Basic Biochemistry and Biomolecules

Scope and importance of biochemistry and molecular biology in plants. Structural and functional organization of prokaryotic and eukaryotic cells, viruses and bacteriophages Cell organelles function and their fractionation. Chemical bonding in biological systems, pH and buffers. Thermodynamics and bioenergetics-concept of entropy and free energy changes in biological reactions, Redox reactions, Role of high energy phosphates. Biomembranes. Classification, structure, chemistry, properties and functions of carbohydrates, proteins, lipidsand nucleic acids. Biochemistry and significance of secondary metabolites. Components of immune system, Prostaglandins.

Unit 2: Intermediary Metabolism

Anabolism, catabolism and their regulation. Metabolic flux, Metabolism of carbohydrates - glycolytic pathway, HMP pathway, TCA cycle, glyoxylate pathway and gluconeogenesis. Biological oxidation-electron transfer and oxidative phosphorylation. Lipid metabolism- degradation and biosynthesis of fatty acids, ketogenesis and causes of ketosis. Biosynthesis of triglycerides, sterols and phospholipids. Amino acid metabolism- catabolism of amino acids, transamination and deamination, urea cycle, biosynthesis of amino acids. Conversion ofamino acids into bioactive compounds. Metabolism of nucleic acids-degradation and biosynthesis of purines, pyrimidines and nucleotides. Integration of carbohydrate, lipid and amino acid metabolism. Signal transduction mechanisms. Role of G-proteins, cyclic nucleotides and calcium in transduction. Disorders of lipid, carbohydrate, nucleic acid, aminoacid metabolism. Inborn errors of metabolism.

Unit 3: Enzymes, Vitamins and Hormones

Classification of enzymes, general properties, kinetics, active site and its mapping, activation energy and transition state. Mechanisms of enzyme action, inhibition and activation. Coenzymes and cofactors. lsoenzymes and immobilized enzymes, Biosensors, Pseudoenzymes, Enzyme Promiscuity, Abzymes. Regulation of enzyme activity, allosteric regulation. Multi substrate reactions, kinetic experiments to determine the mechanism of multi substrate reactions. Isolation, purification and measurement of enzyme activity. Enzyme engineering. Role of enzymes in agriculture, industry, and medicine. Structure, modeof action and metabolic functions of vita mins. Deficiency diseases associated with vitamins. General description of natural hormones and disorders associated with endocrine glands, viz. pituitary, thyroid, adrenal, pancreas and gonads. Peptide and steroid hormones. Phyto hormones -auxins, gibberellins, cytokinins, ethylene, abscisic acid and new plant bio- regulators like Salicylic acid, Brassinosteroids and Strigolactones.

Unit 4: Molecular Biology

Structure of DNA and RNA, Replication, transcription and translation. Posttranscriptional and translational modifications. Transcriptional and translation control of prokaryotes and eukaryotes. Features of genetic code in prokaryotes and eukaryotes. Gene expression -operon model, induction and repression, control of gene expression in prokaryotes and eukaryotes. Chloroplast and Mitochondrial genomes. Replication of viruses. Mutagens, oncogenes and carcinogenesis. General principles of recombinant DNA technology, restriction enzymes., DNA and protein sequence analysis, oligonucleotide synthesis, genomic and cDNA library construction, transposon tagging, chromosome walking. Basics of genome organization and mapping, functional genomics. Computer application in molecular biology, primer designing, sequence analysis and phylogenetic analysis. Benefits of gene manipulation in agriculture, nanobiotechnology, bio-chips.

Unit 5: Techniques in Biochemistry

Principles of optical, phase contrast, fluorescence and electron microscopy, Spectroscopic techniques- X-ray, UV, Visible, NIR, IR, Raman. Fluorimetry, turbidometry and atomic absorption spectrophotometry, ICP (AES, OES, MS). MALDI-TOF, NMR. Radioisotopic techniques- scintillation' counters and autoradiography and their application in biological sciences Electrophoresis -general principles and applications, gel electrophoresis, isoelectric focusing, pulsed field gel electrophoresis, immune-electrophoresis. Chromatographic techniques -paper, thin layer, column chromatography, GC and HPLC. Centrifugation - principles of sedimentation, differential centrifugation, density gradient centrifugation and ultracentrifugation. Cell, tissue and organ culture. Cryopreservation. PCR and application of RFLP, RAPD, AFLP, microsatellite and mitochondrial and ribotyping techniques. Southern, Northern and Western blotting, ELISA. DNA and Protein Microarray. Preliminary methodsof statistical analysis as applied to agricultural data -standard deviation, standard error,ANOVA, correlation and regression.

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Unit 6: Biochemistry of Food grains, Fruits and Vegetables

Fundamentals of nutrition, concept of balanced diet. Recommended dietary allowances. Physicochemical, functional and nutritional characteristics of carbohydrates, proteins and fats. Nutritional quality of proteins and its evaluation. Dietary fibers. Minerals-biochemical functions and deficiency diseases. Fats and lipids-types of fatty acids and their significance in health. Biochemical composition and food value of various food grains (including cereals, pulses, oil seeds), fruits and vegetables. Biochemistry of fruit ripening. Biochemical aspects of post-harvest technology, storage and preservation. Biochemical basis of quality improvement of food grains, vegetables and fruits. Polyphenolics, Antioxidants, nutraceuticals, Anti-nutritional factors. Food toxins and anti-metabolites, Food sensitivity, food additives. Seed storage proteins in cereal grains and legumes. Prebiotics and probiotics. Factors affecting bioavailability of nutrients. Food Sensitivity, Nutraceuticals, Glycemic index, Functional foods

Unit 7: Photosynthesis

Photosynthesis, photosynthetic pigments, light reactions, photosystems. Photophosphorylation, dark reactions: C3, C4 and CAM pathways. Regulation of Rubisco. Chemiosmotic coupling. Carbon cycle and its regulation, Ion fluxes and conformational changes during photosynthesis. Photorespiration. Relationship between photosynthesis, photorespiration and crop productivity. Chloroplast morphology, structure and biochemical anatomy. Cytosolic and organelle interactions. Nature and exchange of metabolites through translocators. Seed reserve biosynthesis.

Unit 8: Plant Metabolic Processes

Uptake and metabolism of mineral nutrients in plants. Sulphur metabolism. Nitrogen cycle, nitrate and nitrite reduction, denitrification, symbiotic and non-symbiotic nitrogen fixation. Biochemical and physiological role of hydrogenase. Chemoautotrophy in rhizobia and nitrifying bacteria. Cell cycle. Growth regulation in plants. Signal transduction and phytohormones. Biochemical mechanisms of plant growth, hormone action, biotic and abioticstresses. Role of oligosaccharides and polysaccharides in cellular metabolism. Metabolism of cyanogenic glycosides and glucosinolates. Biochemistry of seed germination.

Unit 9: Plant Molecular Biology

General organization of nuclear, mitochondrial and chloroplast genomes. Genomics andfunctional genomics, Epigenetics and Epigenomics. Tissue specific expression of genes.Molecular biology of various stresses -drought, salinity and temperature. Signal transduction and its molecular basis: molecular mechanism of plant hormone action. Structure,organization and regulation of nuclear genes. Genes involved in photosynthesis and nitrogen fixation. Regulation of chloroplast gene expression. Mitochondrial control of fertility. High-Throughput Sequencing (HTS) techniques, Small RNAs, RNA interference, Molecularmarkers in plants and their uses.

Unit 10: Plant Biotechnology / Genetic Engineering

Totipotency, application of tissue culture for plant improvement, cryopreservation. Protoplasm fusion. General principles of gene cloning. Isolation and characterization of plant genes and promoters. Different methods of gene transfer -direct and vector mediated. Gene silencing. Site directed mutagenesis, Gene editing. Molecular analysis of transformants. Potential applications of plant genetic engineering for crop improvement -insect-pest resistance (insect, viral, fungal and bacterial diseases). Abiotic stress tolerance, herbicide resistance, nutritional quality improvement, increasing shelf-life, oil quality. Biosafety andIPR issues.

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CHAPTER 01
Basic Biochemistry and Biomolecules

2023

1. Which non-covalent interaction is primarily responsible for the stabilization of the DNA double helix core by minimizing exposure of nonpolar bases to water?
(A) Ionic bonding
(B) Hydrogen bonding
(C) Disulfide linkages
(D) Hydrophobic effect

2022

2. According to the Henderson-Hasselbalch equation, when the pH of a solution equals the pKa of the weak acid, what is the ratio of conjugate base to weak acid?
(A) 0:1
(B) 1:10
(C) 1:1
(D) 10:1

2019

3. Which of the following structural features is present in eukaryotic cells but strictly absent in prokaryotic cells?
(A) Ribosomes
(B) Membrane-bound nucleus
(C) Plasma membrane
(D) Peptidoglycan cell wall

2009

4. Identify the INCORRECT statement regarding bacteriophage replication.
(A) The lytic cycle culminates in the destruction of the host cell.
(B) In the lysogenic cycle, viral DNA integrates into the host genome.
(C) Environmental stress can trigger a switch from lysogeny to the lytic cycle.
(D) Prophages undergo continuous active replication independent of host division.

2018

5. Which of the following is the most appropriate primary function of the Golgi apparatus in eukaryotic cells?
(A) Modification, sorting, and packaging of proteins
(B) Synthesis of ribosomal RNA
(C) Generation of ATP via oxidative phosphorylation
(D) Breakdown of toxic cellular metabolites

2015

6. During subcellular fractionation by differential centrifugation, which organelle typically sediments first at the lowest speeds (e.g., 1000 x g)?
(A) Mitochondria
(B) Ribosomes
(C) Nuclei
(D) Endoplasmic reticulum vesicles

2015

7. Which of the following conditions indicates a thermodynamically spontaneous reaction under standard conditions?
(A) $\Delta G^{\circ} < 0$
(B) $\Delta G^{\circ} > 0$
(C) $\Delta G^{\circ} = 0$
(D) $\Delta H^{\circ} > 0$

2015

8. What is the effect of a positive standard reduction potential (ΔE°) on the standard free energy change (ΔG°) of a redox reaction?
(A) It makes ΔG° positive, indicating a non-spontaneous reaction.
(B) It has no effect on ΔG°.
(C) It causes the reaction to reach equilibrium immediately.
(D) It makes ΔG° negative, indicating a spontaneous reaction.

2008

9. ATP hydrolysis is highly exergonic. Which classification best describes the bonds broken during this process to release energy?
(A) Phosphodiester bonds
(B) Phosphoanhydride bonds
(C) Thioester bonds
(D) Glycosidic bonds

2006

10. Consider the following statements regarding the fluid mosaic model of biological membranes:
I. Phospholipids can undergo rapid lateral

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diffusion.
II. Transverse diffusion (flip-flop) of lipids is highly frequent and unassisted.
III. Integral membrane proteins are embedded within the lipid bilayer.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

2023

11. How does secondary active transport differ from primary active transport?
(A) It moves molecular species along their respective concentration gradients.
(B) It relies directly on the immediate hydrolysis of cellular ATP molecules.
(C) It mediates only the transport of water across lipid bilayers in the cell.
(D) It uses electrochemical gradients established by a primary pump mechanism.

2008

12. D-glucose and D-galactose differ in the configuration at a single chiral center. Which term best describes their relationship?
(A) Epimers
(B) Enantiomers
(C) Anomers
(D) Conformers

2005

13. Which of the following polysaccharides is correctly paired with its primary glycosidic linkage?
(A) Cellulose - $\alpha(1\rightarrow4)$
(B) Glycogen - $\alpha(1\rightarrow4)$ and $\alpha(1\rightarrow6)$
(C) Amylose - $\beta(1\rightarrow4)$
(D) Chitin - $\alpha(1\rightarrow6)$

2021

14. Which amino acid does not exhibit stereoisomerism at the alpha-carbon?
(A) Alanine
(B) Glycine
(C) Proline
(D) Valine

2011

15. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : The alpha-helix structure of proteins is stabilized by hydrogen bonds between the carbonyl oxygen and the amide hydrogen of the same polypeptide chain.
Reason (R) : Proline is frequently found within the central regions of alpha-helices because its rigid ring structure enhances helical stability.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2025

16. In the tertiary structure of proteins, which interaction is characterized as a covalent bond?
(A) Van der Waals forces
(B) Hydrophobic interactions
(C) Disulfide bridges
(D) Salt bridges

2013

17. Which of the following fatty acids contains multiple double bonds?
(A) Palmitic acid
(B) Stearic acid
(C) Myristic acid
(D) Arachidonic acid

2009

18. Identify the correct pair regarding membrane lipids.
(A) Sphingomyelin - Glycerol backbone
(B) Phosphatidylcholine - Sphingosine backbone
(C) Cholesterol - Steroid nucleus
(D) Cerebroside - Multiple phosphate groups

2022

19. Identify the INCORRECT pair regarding nucleic acid structure.
(A) A-DNA - Right-handed helix
(B) B-DNA - Right-handed helix
(C) Z-DNA - Left-handed helix
(D) Z-DNA - Broadest helix diameter

2012

20. Consider the following statements about RNA molecules:
I. mRNA carries genetic information from DNA to ribosomes.
II. tRNA acts as an adapter molecule during translation.
III. rRNA is a structural and catalytic component of ribosomes.
IV. Ribozymes are RNA molecules devoid of any enzymatic activity.
Which of the above statement(s) is/are correct?

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(A) I, II and IV
(B) I, III and IV
(C) I, II and III
(D) II, III and IV

2019

21. Which plant secondary metabolites are derived primarily from the mevalonate or non-mevalonate (MEP) pathways?
(A) Alkaloids
(B) Phenolics
(C) Terpenoids
(D) Flavonoids

2007

22. Which enzyme is most relevant to the initial conversion of arachidonic acid into prostaglandins?
(A) Lipoxygenase
(B) Cyclooxygenase
(C) Phospholipase A2
(D) Thromboxane synthase

2017

23. Identify the correct statement regarding immunoglobulins.
(A) IgG is the primary pentameric antibody in serum.
(B) IgM is mainly found in mucosal secretions.
(C) IgA is the most abundant immunoglobulin in primary responses.
(D) IgE is primarily involved in allergic responses.

2018

24. Which parameter represents the enthalpy change of a biochemical system?
(A) ΔG
(B) ΔH
(C) ΔS
(D) ΔE

2012

25. Match the cellular organelles in List I with their functions in List II and select the correct option.
List I : (Cellular Organelles)
P. Mitochondria
Q. Lysosomes
R. Smooth ER
S. Nucleolus
List II : (Functions)
1. Lipid synthesis
2. Ribosome synthesis
3. ATP production
4. Macromolecule degradation
(A) P-3, Q-4, R-1, S-2
(B) P-3, Q-2, R-1, S-4
(C) P-1, Q-4, R-3, S-2
(D) P-4, Q-3, R-1, S-2

2022

26. Which of the following is NOT a characteristic of the hydrophobic effect?
(A) It drives the folding of globular proteins.
(B) It involves the structuring of water molecules around nonpolar solutes.
(C) It is driven by a decrease in the entropy of the system upon folding.
(D) It stabilizes the lipid bilayer formation.

2018

27. When applying the Nernst equation to biological membranes, what is primarily determined?
(A) The equilibrium potential for a specific ion
(B) The rate of ion transport
(C) The number of transport proteins present
(D) The ATP consumption rate of pumps

2018

28. Which definition best describes a zwitterion in the context of amino acids?
(A) A chemical species containing exclusively positive functional groups.
(B) A molecule that lacks any charged functional groups at any pH level.
(C) A molecular ion that spontaneously forms covalent bonds with water.
(D) A neutral molecule with spatially separated positive and negative charges.

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2006

29. What causes mutarotation in aqueous solutions of monosaccharides?
(A) Oxidation of the terminal aldehyde group
(B) Interconversion between alpha and beta anomeric forms
(C) Reduction of the ketone group
(D) Epimerization at the C-2 position

2004

30. Consider the following statements regarding the structural architecture of chloroplasts:
I. They possess a double membrane envelope.
II. Thylakoid membranes contain photosynthetic pigments.
III. The stroma is the site of light-dependent reactions.
IV. They contain their own circular DNA.
V. Granum refers to a stack of thylakoids.
Which of the above statement(s) is/are INCORRECT?
(A) I and II

(B) III only
(C) IV and V
(D) II and V

2001

31. Which of the following structural forms of DNA is favored in alternating purine-pyrimidine sequences under high salt conditions?
(A) A-DNA
(B) B-DNA
(C) H-DNA
(D) Z-DNA

2025

32. Which phenomenon is an advantage of employing differential centrifugation?
(A) It separates particles based on sedimentation rate and size.
(B) It allows precise separation of organelles of identical sizes.
(C) It relies solely on the density of the particles.
(D) It requires no specialized equipment.

2006

33. Based on inference, why are biological membranes asymmetrical?
(A) To allow free flipping of all lipid types
(B) To maintain distinct intracellular and extracellular signaling functions
(C) To ensure uniform membrane thickness
(D) To prevent the insertion of integral proteins

2017

34. Eliminate the INCORRECT option regarding physiological buffer systems.
(A) The bicarbonate buffer is crucial in blood plasma.
(B) Phosphate buffers are major intracellular buffering agents.
(C) Proteins can act as buffers due to their ionizable side chains.
(D) Acetate is the primary buffering agent in human erythrocytes.

2018

35. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : Saturated fatty acids have higher melting points than unsaturated fatty acids of the same chain length.
Reason (R) : Saturated fatty acids contain cis-double bonds that create kinks, preventing tight packing.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2006

36. Which structural component is specific to Gram-negative prokaryotic cells compared to Gram-positive ones?
(A) Thick peptidoglycan layer
(B) Teichoic acids
(C) Plasma membrane
(D) Outer membrane containing lipopolysaccharides

2012

37. Identify the correct statement about the Ramachandran plot.
(A) It plots the phi (ϕ) and psi (ψ) dihedral angles of amino acid residues.
(B) It plots the molecular weight against the sedimentation coefficient.
(C) All regions of the plot are sterically allowed for all amino acids.
(D) Glycine has the most restricted conformational space on the plot.

2017

38. Which of the following is an established organelle-specific marker enzyme for mitochondria?
(A) Acid phosphatase
(B) Glucose-6-phosphatase
(C) Catalase
(D) Succinate dehydrogenase

2016

39. Identify the INCORRECT statement regarding the Watson-Crick double-helical model.
(A) The two strands are antiparallel.
(B) Adenine pairs with Thymine via two hydrogen bonds.
(C) Guanine pairs with Cytosine via two hydrogen bonds.
(D) The sugar-phosphate backbone is on the exterior.

2007

40. Select the correct sequence of events in the lytic cycle of a bacteriophage.
(A) Attachment, Penetration, Biosynthesis, Maturation, Lysis
(B) Penetration, Attachment, Maturation, Biosynthesis, Lysis
(C) Attachment, Maturation, Penetration, Biosynthesis, Lysis

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(D) Biosynthesis, Penetration, Attachment, Lysis, Maturation

2012

41. Which physical property increases as the carbon chain length of a saturated fatty acid increases?
(A) Solubility in water
(B) Melting point
(C) Number of double bonds
(D) Polarity

2012

42. What is the standard classification for an amino acid containing a hydroxyl group in its side chain?
(A) Polar uncharged
(B) Nonpolar aliphatic
(C) Positively charged
(D) Negatively charged

2018

43. Which process requires a membrane transport protein but no direct energy input?
(A) Simple diffusion
(B) Primary active transport
(C) Endocytosis
(D) Facilitated diffusion

2001

44. What defines an epimer?
(A) Sugars differing in the length of the carbon chain
(B) Sugars differing only in the configuration around one specific carbon atom
(C) Aldose-ketose isomers
(D) Molecules with different chemical formulas

2002

45. Match the plant secondary metabolites in List I with their defining characteristics in List II and select the correct option.
List I : (Secondary Metabolites)
P. Alkaloids
Q. Phenolics
R. Terpenoids
S. Glycosides (General)
List II : (Characteristics)
1. Isoprene units
2. Nitrogen-containing ring structures
3. Hydroxyl group attached to an aromatic ring
4. Sugar attached to a non-sugar moiety
(A) P-2, Q-3, R-1, S-4
(B) P-3, Q-2, R-4, S-1
(C) P-1, Q-4, R-3, S-2
(D) P-2, Q-1, R-3, S-4

2006

46. Identify the correct pair representing a cell organelle and its principal biochemical function.
(A) Rough ER - Detoxification of lipids
(B) Smooth ER - Protein synthesis
(C) Vacuole - Storage and turgor maintenance
(D) Lysosome - ATP synthesis

2008

47. Which basic law of thermodynamics states that the total energy of an isolated system is constant?
(A) First Law
(B) Zeroth Law
(C) Second Law
(D) Third Law

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2019

48. Identify the INCORRECT pair regarding cellular components of the immune system.
(A) T-cells - Cell-mediated immunity
(B) B-cells - Antibody production
(C) Macrophages - Phagocytosis
(D) Plasma cells - Direct targeted cell lysis

2015

49. By what mechanism do ionophores facilitate transport across biological membranes?
(A) By directly hydrolyzing ATP to pump ions
(B) By increasing the permeability of the membrane to specific ions
(C) By stiffening the lipid bilayer
(D) By binding to nuclear receptors

2021

50. Consider the following statements about protein quaternary structure:
I. It involves the assembly of multiple polypeptide subunits.
II. It is primarily stabilized by peptide bonds between subunits.
III. Hemoglobin is a classic example of a protein with quaternary structure.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

2024

51. Which factor is most relevant to determining membrane fluidity?
(A) The concentration of internal calcium ions
(B) The ratio of saturated to unsaturated fatty acid tails
(C) The rate of ATP production

(D) The number of ribosomes attached to the ER

2002

52. What causes the characteristic sigmoidal binding curve of oxygen to hemoglobin compared to myoglobin?
(A) Cooperative binding among quaternary subunits
(B) Denaturation of the subunits
(C) Competitive inhibition by carbon dioxide
(D) Covalent modification of the heme group

2007

53. Which term refers to the pH at which an amino acid carries no net electrical charge?
(A) pKa
(B) Neutralization point
(C) Isoelectric point (pI)
(D) Equilibrium pH

2016

54. Which of the following is NOT a structural polysaccharide?
(A) Cellulose
(B) Starch
(C) Chitin
(D) Hemicellulose

2008

55. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : The inner mitochondrial membrane is highly impermeable to most ions and polar molecules.
Reason (R) : This impermeability is essential to maintain the proton gradient required for ATP synthesis.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2007

56. What distinguishes a nucleotide from a nucleoside?
(A) The presence of one or more phosphate groups
(B) The presence of a nitrogenous base
(C) The presence of a pentose sugar
(D) The presence of a glycosidic bond

2011

57. Which type of RNA acts as the catalytic component in the peptide bond formation during translation?
(A) mRNA
(B) tRNA
(C) rRNA
(D) snRNA

2025

58. Identify the correct statement about eicosanoids.
(A) They are synthesized exclusively from cholesterol.
(B) They function primarily as long-distance endocrine hormones.
(C) They are derived from 20-carbon polyunsaturated fatty acids like arachidonic acid.
(D) They are the primary storage form of energy in adipocytes.

2007

59. Which class of biomolecules exhibits a general formula of $(CH_2O)_n$?
(A) Proteins
(B) Lipids
(C) Nucleic acids
(D) Carbohydrates

2015

60. Consider the following statements about the hydrophobic effect:
I. It is an entropic phenomenon.
II. It drives the formation of lipid bilayers.
III. It results in a decrease in the entropy of the surrounding water molecules when lipids aggregate.
IV. It plays a major role in protein folding.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, III and IV
(C) II, III and IV
(D) I, II, III and IV

2007

61. How does the structure of a glycerophospholipid differ from a triacylglycerol?
(A) One fatty acid chain is replaced by a phosphate and a polar head group.
(B) It contains three fatty acid chains instead of two.
(C) It lacks a glycerol backbone.
(D) It contains a steroid nucleus.

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2004

62. Which of the following is least relevant to the biological function of plant phenolics?
(A) Primary structural component of the cell membrane
(B) Defense against herbivores
(C) Attraction of pollinators
(D) Protection against UV radiation

2016

63. Identify the INCORRECT statement concerning T-cells.
(A) They mature in the thymus.
(B) They secrete large amounts of circulating antibodies.
(C) Helper T-cells express CD4 receptors.
(D) Cytotoxic T-cells express CD8 receptors.

2008

64. What is the fundamental driving force for the spontaneous folding of water-soluble globular proteins?
(A) Maximization of solvent-exposed hydrophobic surface area
(B) Hydrophobic collapse hiding nonpolar residues from water
(C) Formation of internal hydrogen bonds
(D) Formation of internal disulfide bonds

2011

65. Match the immune components in List I with their defining features in List II and select the correct option.
List I : (Immune Components)
P. Antigens
Q. Immunoglobulins
R. Macrophages
S. B-cells
List II : (Defining Features)
1. Phagocytic cells of the innate immune system
2. Molecules that elicit an immune response
3. Cells that mature in the bone marrow and produce antibodies
4. Glycoproteins that bind specifically to antigens
(A) P-2, Q-4, R-1, S-3
(B) P-4, Q-2, R-1, S-3
(C) P-2, Q-1, R-4, S-3
(D) P-1, Q-4, R-3, S-2

2025

66. In an endergonic biological reaction, how is the required energy typically supplied?
(A) By raising the physiological temperature of the cell
(B) By coupling to a highly exergonic reaction like ATP hydrolysis
(C) By lowering the activation energy through purely physical means
(D) By spontaneous reversal of the reaction

2009

67. Which of the following electron carrier molecules transfers electrons specifically in its reduced form?
(A) NADH
(B) NAD^+
(C) FAD
(D) $NADP^+$

2010

68. Which of the following represents a definition of an essential fatty acid?
(A) A fatty acid providing no energetic value to the organism.
(B) A fatty acid containing no double bonds in its carbon chain.
(C) A fatty acid required solely for the synthesis of cellular ATP.
(D) A fatty acid that must be obtained through dietary intake.

NODIA

2007

69. Based on structural features, how is a bacteriophage generally classified?
(A) By its lipid envelope solely
(B) By its specific infectivity toward bacterial cells
(C) By its ability to synthesize proteins independently
(D) By its lack of a genome

2003

70. Consider the following statements about membrane transport:
I. Passive diffusion requires no carrier protein.
II. Facilitated diffusion is saturable.
III. Primary active transport hydrolyzes ATP.
IV. Secondary active transport uses an established ion gradient.
V. Ionophores decrease membrane permeability to ions.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) V only
(C) III and IV
(D) II and V

2013

71. What is the Gibbs free energy change (ΔG) of a reaction when it has reached equilibrium?
(A) Greater than 1
(B) Less than 0
(C) Exactly 0
(D) Equal to the gas constant

2007

72. Which functional role is primarily associated with transfer RNA (tRNA)?
(A) Splicing of mRNA transcripts
(B) Serving as the structural core of the ribosome
(C) Transporting genetic information from the nucleus
(D) Carrying specific amino acids to the ribosome

2025

73. Identify the INCORRECT statement regarding protein domains.
(A) They are independent folding units within a polypeptide.
(B) They often possess distinct functional properties.
(C) A single polypeptide can contain multiple domains.
(D) They are synonymous with protein quaternary structure.

2003

74. Which physical parameter is directly calculated using the Henderson-Hasselbalch equation?
(A) Enzyme velocity
(B) Sedimentation rate
(C) Solution pH based on buffer concentration ratios
(D) Standard free energy

2015

75. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : Chitin is a rigid and strong structural polysaccharide found in the exoskeletons of insects.
Reason (R) : Chitin is composed of repeating N-acetylglucosamine units linked by $\beta(1_{\rightarrow}4)$ glycosidic bonds.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2017

76. In an alpha-helix, how many amino acid residues are typically present per turn?
(A) 3.6
(B) 2.0
(C) 4.5
(D) 5.4

2021

77. Which process demonstrates the concept of mutarotation?
(A) The change in optical rotation of a sugar solution until equilibrium is reached
(B) The shifting of double bonds in fatty acids
(C) The denaturation of a protein helix
(D) The rapid movement of lipids across a bilayer

2007

78. Which of the following identifies a correct pair?
(A) Ribozyme - Protein catalyst
(B) mRNA - Contains anticodons
(C) tRNA - Synthesized in the cytoplasm solely
(D) rRNA - Catalytic core of ribosomes

2022

79. Identify the INCORRECT pair regarding cell organelles and their features.
(A) Nucleus - Double membrane
(B) Mitochondria - Circular DNA
(C) Chloroplast - Thylakoids
(D) Lysosome - Alkaline pH interior

2003

80. Select the correct sequence for the calculation of an isoelectric point (pI) for a neutral amino acid like glycine.
(A) Identify pK1 and pK2, add them, multiply by 2
(B) Identify pK_1 and pK_2, add them, divide by 2
(C) Identify pK_1 and pK_R, add them, divide by 2
(D) Identify pK_2 and pK_R, add them, divide by 2

2007

81. Which bond provides the most significant thermodynamic drive for coupled metabolic reactions?
(A) The high-energy phosphoanhydride bond in ATP
(B) The peptide bond in proteins
(C) The hydrogen bond in water
(D) The ester bond in triacylglycerols

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2014

82. Which of the following is an amphipathic molecule?
(A) Triacylglycerol
(B) Benzene
(C) Glycine at pH 7
(D) Glycerophospholipid

2018

83. By eliminating the INCORRECT options, determine which of the following is an exclusively pyrimidine base found in DNA.
(A) Adenine
(B) Guanine
(C) Cytosine
(D) Uracil

2012

84. What is a disadvantage of an uncatalyzed biological reaction compared to an enzymatically catalyzed one?
(A) The activation energy barrier is too high for physiological rates.
(B) The standard free energy change is drastically altered.
(C) The equilibrium constant shifts to the left.
(D) The reaction becomes inherently non-spontaneous.

2014

85. Match the lipid classifications in List I with their specific examples in List II and select the correct option.
List I : (Lipid Classifications)
P. Glycerophospholipid
Q. Sphingolipid
R. Sterol
S. Eicosanoid
List II : (Specific Examples)
1. Cholesterol
2. Phosphatidylserine
3. Prostaglandin E_2
4. Ceramide
(A) P-2, Q-4, R-1, S-3
(B) P-4, Q-2, R-1, S-3
(C) P-2, Q-1, R-4, S-3
(D) P-1, Q-4, R-3, S-2

2019

86. Which factor directly decreases the fluidity of a biological membrane at physiological temperatures?
(A) Increased proportion of unsaturated fatty acids
(B) Increased presence of cholesterol
(C) Increased temperature
(D) Decreased length of fatty acid chains

2002

87. What is the fundamental cause of the formation of an electrochemical gradient across a cell membrane?
(A) Unequal distribution of ions and electrical charges across the lipid bilayer
(B) Equal distribution of uncharged molecules
(C) Rapid lateral diffusion of lipids
(D) The rigid structure of the cell wall

2022

88. Which characteristic defines the $FAD/FADH_2$ redox couple compared to NAD+/NADH?
(A) FAD is purely a single-electron carrier.
(B) $FADH_2$ is exclusively found in the cytoplasm.
(C) $FADH_2$ operates at a highly negative standard reduction potential compared to NADH.
(D) FAD is typically covalently or tightly bound to its respective enzyme.

NODIA

2007

89. Which of the following correctly classifies glycogen?
(A) Linear structural polysaccharide
(B) Branched storage polysaccharide
(C) Branched structural polysaccharide
(D) Linear storage polysaccharide

2025

90. Consider the following statements about secondary metabolites:
I. Alkaloids often contain a basic nitrogen atom.
II. Terpenoids are assembled from isoprene units.
III. Phenolics lack aromatic rings.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

2005

91. Which of the following describes the secondary structure known as a beta-turn?
(A) A long extended polypeptide chain with no secondary structure.
(B) A coiled-coil motif involving two interacting alpha helices.
(C) A beta-sheet structure containing parallel polypeptide strands.
(D) A compact reversal of chain direction involving four residues.

2011

92. Based on its pKa values, what is the predominant charge of aspartic acid at physiological pH (7.4)?
(A) +1
(B) 0
(C) -1
(D) -2

2017

93. Identify the INCORRECT statement regarding protein denaturation.
(A) It involves the disruption of secondary and tertiary structures.
(B) It invariably breaks the primary peptide bonds.
(C) It can be caused by extreme pH or temperature.
(D) It often leads to a loss of biological function.

2001

94. Which class of membrane transporters moves two different molecules in opposite directions across the membrane?
(A) Uniporters
(B) Symporters
(C) Antiporters
(D) Ion channels

2017

95. The following question consists of two statements—Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : The melting point of oleic acid (18:1) is lower than that of stearic acid (18:0).
Reason (R) : The cis-double bond in oleic acid introduces a bend in the hydrocarbon chain, disrupting tight intermolecular packing.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2017

96. What defines a thioester bond?
(A) A linkage between a carboxylic acid and a thiol group
(B) A linkage between two hydroxyl groups
(C) A bond between a phosphate and a sugar
(D) A bond between two amino acids

2003

97. Which structural feature primarily contributes to the amphipathic nature of sterols like cholesterol?
(A) The single hydroxyl group at position C-3
(B) The rigid four-ring steroid nucleus
(C) The short aliphatic side chain
(D) The presence of double bonds in the rings

2018

98. Which of the following sets of bases represents the purines found in both DNA and RNA?
(A) Cytosine and Thymine
(B) Adenine and Guanine
(C) Uracil and Cytosine
(D) Adenine and Uracil

NODIA

2005

99. Identify the INCORRECT statement regarding thermodynamic parameters.
(A) ΔG - Free energy change
(B) ΔH - Enthalpy change
(C) T - Absolute temperature
(D) ΔS - Entropy change

2017

100. Consider the following statements about membrane asymmetry:
I. Lipids are evenly distributed between the inner and outer leaflets.
II. Phosphatidylserine is typically restricted to the inner leaflet in healthy cells.
III. Glycolipids are predominantly found on the extracellular leaflet.
IV. Flippases help maintain this asymmetry.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) II, III and IV
(C) I, III and IV
(D) I, II and III

2006

101. Which term describes the process of separating subcellular components based strictly on their sedimentation rates under varying centrifugal forces?
(A) Differential centrifugation
(B) Density gradient centrifugation
(C) Isopycnic centrifugation
(D) Electrophoresis

2005

102. Which form of RNA contains extensive modified bases and exhibits a characteristic cloverleaf secondary structure?
(A) mRNA

(B) 16S rRNA
(C) snRNA
(D) tRNA

2004

103. Is the most appropriate definition of an antigen?
(A) A protein produced by plasma cells
(B) A cell that engulfs foreign particles
(C) A molecule capable of inducing an immune response
(D) A chemical messenger of the immune system

2012

104. What primarily determines the specific compartmentalization of metabolic pathways in eukaryotic cells?
(A) The random diffusion of enzymes
(B) The uniform distribution of ATP
(C) The size of the metabolites
(D) The presence of organelle-specific membrane barriers and local environments

2011

105. Match the biochemical equations/principles in List I with their applications in List II and select the correct option.
List I : (Equations/Principles)
P. Henderson-Hasselbalch equation
Q. Nernst equation
R. Gibbs free energy equation
S. Ramachandran plot
List II : (Applications)
1. Predicting protein backbone conformation
2. Calculating standard reduction potentials and cell voltage
3. Determining the pH of a buffer solution
4. Predicting reaction spontaneity
(A) P-3, Q-2, R-4, S-1
(B) P-2, Q-3, R-4, S-1
(C) P-3, Q-2, R-1, S-4
(D) P-4, Q-1, R-2, S-3

2006

106. Which metabolic precursor is strictly required for the biosynthesis of prostaglandins?
(A) Cholesterol
(B) Isopentenyl pyrophosphate
(C) Tyrosine
(D) Arachidonic acid

2004

107. By what mechanism does a physiological buffer system resist large changes in pH?
(A) By containing significant amounts of a weak acid and its conjugate base to absorb added H+ or OH-
(B) By completely neutralizing added strong acids with water
(C) By precipitating out of solution upon addition of an acid
(D) By accelerating metabolic pathways that consume protons

2001

108. Which is a characteristic feature of viral structures?
(A) They possess both DNA and RNA in a single virion.
(B) They actively produce ATP for replication.
(C) They synthesize their own ribosomes.
(D) They are enclosed in a protein coat known as a capsid.

2005

109. Which sequence best categorizes the order of organelle sedimentation from highest density/ size to lowest during differential centrifugation?
(A) Nuclei, Mitochondria, Microsomes, Cytosol
(B) Mitochondria, Nuclei, Microsomes, Cytosol
(C) Microsomes, Mitochondria, Nuclei, Cytosol
(D) Cytosol, Microsomes, Mitochondria, Nuclei

2015

110. Consider the following statements:
I. Oxidation is a gain of electrons.
II. Reduction is a loss of electrons.
III. NAD+ is a biological electron carrier.
IV. Standard reduction potentials predict electron flow direction.
V. FAD is reduced to FADH2.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) III and IV
(C) IV and V
(D) I and III

2005

111. Which form of standard free energy change specifically applies to biochemical standard state conditions (pH 7)?
(A) ΔG
(B) ΔG°
(C) ΔH°
(D) $\Delta G'^{\circ}$

2022

112. Identify the correct statement regarding hydrophobic interactions.
(A) They arise from the tendency of water molecules to maximize their own entropy.

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(B) They are true chemical bonds involving electron sharing.
(C) They are strongest in non-polar solvents.
(D) They result from electrostatic attraction between opposite charges.

2013

113. Which definition best explains standard reduction potential?
(A) The heat released during a redox reaction
(B) The measure of a molecule's tendency to donate or accept electrons
(C) The speed at which electrons are transferred
(D) The concentration of an electron carrier at equilibrium

2024

114. Eliminate the INCORRECT option regarding the function of the rough endoplasmic reticulum.
(A) It is studded with ribosomes.
(B) It is the primary site of intracellular lipid synthesis.
(C) It is involved in the synthesis of secreted proteins.
(D) It participates in early stages of protein glycosylation.

2011

115. What is an advantage of employing gradient centrifugation over differential centrifugation?
(A) Separates organelles based on their specific buoyant densities.
(B) Requires significantly less time and specialized lab equipment.
(C) Eliminates the need to disrupt cells before the process begins.
(D) Operates independently of the application of centrifugal force.

2017

116. Which term is used to describe an amino acid that has both a basic amino group and an acidic carboxyl group ionized?
(A) Anion
(B) Cation
(C) Zwitterion
(D) Isomer

2024

117. What distinguishes secondary structure from tertiary structure in proteins?
(A) Secondary is local folding, while tertiary is the 3D shape.
(B) Secondary involves side-chain bonds, while tertiary is backbone-based.
(C) Secondary structure requires the assembly of multiple polypeptides.
(D) Tertiary structure is stabilized exclusively by primary peptide bonds.

2002

118. Which pair correctly identifies an essential fatty acid and its corresponding omega classification?
(A) Linoleic acid - Omega-3
(B) Arachidonic acid - Omega-9
(C) Oleic acid - Omega-6
(D) Alpha-linolenic acid - Omega-3

2013

119. Identify the INCORRECT statement regarding nucleic acid components.
(A) Adenine - Purine
(B) Uracil - Pyrimidine
(C) Ribose - Pentose sugar
(D) Phosphodiester bond - Linkage between bases

NODIA

2016

120. Determine the correct order of structural organization in proteins, then select the matching option.
I. Tertiary structure
II. Primary structure
III. Quaternary structure
IV. Secondary structure
(A) II, IV, I, III
(B) II, I, IV, III
(C) IV, II, I, III
(D) I, II, III, IV

2003

121. Which secondary metabolite class relies heavily on the shikimate pathway for its biosynthesis?
(A) Alkaloids
(B) Terpenoids
(C) Phenolics
(D) Sterols

2007

122. Which physiological signaling role is most characteristic of prostaglandins?
(A) Mediating inflammation and smooth muscle contraction
(B) Serving as primary intracellular energy stores
(C) Providing structural rigidity to plant cell walls
(D) Acting as long-term storage forms of nitrogen

2006

123. Identify the correct statement regarding B-cells.
(A) They require maturation in the thymus.

(B) They are primarily responsible for cell-mediated immunity.
(C) They destroy virus-infected cells through direct physical contact.
(D) Upon activation, they differentiate into antibody-secreting plasma cells.

2008

124. Which type of bond connects the anomeric carbon of one sugar to a hydroxyl group of another?
(A) Peptide bond
(B) Phosphodiester bond
(C) Ester bond
(D) Glycosidic bond

2014

125. Which parameter represents a state function in biological thermodynamics?
(A) Work done
(B) Heat transferred
(C) Enthalpy (H)
(D) Path of the reaction

2019

126. Which structural feature characterizes a sphingolipid?
(A) A glycerol backbone attached to three fatty acids
(B) A sphingosine backbone attached to a fatty acid via an amide bond
(C) A multiple-ring steroid structure
(D) A continuous long unbranched hydrocarbon chain lacking any functional groups

2014

127. What is the fundamental role of the hydrophobic effect in biomembrane architecture?
(A) Directly forces the polar head groups to hide from water.
(B) Promotes the rapid transverse diffusion of membranes.
(C) Prevents integral proteins from embedding in lipids.
(D) Stabilizes the bilayer by driving nonpolar tails from water.

2023

128. What distinguishes primary active transport from facilitated diffusion?
(A) Facilitates solute movement down specific concentration gradients.
(B) Uses ATP to move solutes against concentration gradients.
(C) Functions without the requirement of a specific transport protein.
(D) Transports only uncharged molecular species across the membrane.

2025

129. Which definition accurately describes a mutarotation process?
(A) The spontaneous conversion between enantiomeric forms of a sugar.
(B) Change in rotation due to anomer interconversion in solution.
(C) The enzymatic hydrolysis of disaccharides into monosaccharides.
(D) The polymerization of glucose units into the glycogen molecule.

2008

130. Based on structural features, how do amylose and amylopectin differ?
(A) Amylose is a structural carbohydrate, while amylopectin is for storage.
(B) Amylose is a linear polymer, while amylopectin is branched.
(C) Amylose is found in animals, while amylopectin is found in plants.
(D) Amylose contains beta linkages, whereas amylopectin contains alpha bonds.

2017

131. Which of the following is an imino acid rather than a standard amino acid, fundamentally affecting protein secondary structure?
(A) Histidine
(B) Proline
(C) Arginine
(D) Tryptophan

2012

132. How do parallel and antiparallel beta-sheets differ in stability?
(A) Antiparallel sheets are more stable due to linear H-bonds.
(B) Parallel sheets are more stable due to linear H-bonds.
(C) They are equally stable and rely on identical bond angles.
(D) Antiparallel sheets lack hydrogen bonding entirely.

2006

133. Which thermodynamic factor primarily drives the denaturation of a protein upon heating?
(A) A decrease in system entropy
(B) The breaking of strong covalent peptide bonds
(C) An increase in hydrophobic interactions
(D) The increase in the kinetic energy overcoming

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non-covalent stabilizing forces

2021

134. Eliminate the INCORRECT statement regarding fatty acid nomenclature.
(A) 18:0 indicates a fatty acid with 18 carbons and no double bonds.
(B) 18:2($\Delta^{9,12}$) indicates double bonds at carbon 9 and 12 from the carboxyl end.
(C) The omega-carbon is the carboxyl carbon.
(D) Essential fatty acids often have double bonds beyond carbon 9.

2005

135. Which class of complex lipids forms the basis for the human ABO blood group antigens on the red blood cell surface?
(A) Sphingoglycolipids (Sphingolipids with carbohydrate heads)
(B) Triacylglycerols
(C) Phosphatidylserines
(D) Sterols

2006

136. Which force is least relevant to the stabilization of the DNA double helix?
(A) Hydrogen bonding between complementary bases
(B) Base-stacking interactions (van der Waals)
(C) Hydrophobic effect shielding the bases
(D) Covalent bonding between complementary bases

2008

137. Which functional role is primarily attributed to small nuclear RNAs (snRNAs)?
(A) Carrying amino acids
(B) Splicing of pre-mRNA transcripts
(C) Serving as the primary genetic material in retroviruses
(D) Providing the structural core of the ribosome

2008

138. Which structural property is a defining characteristic of plant alkaloids?
(A) The presence of a basic nitrogen atom, typically within a heterocyclic ring
(B) The presence of exclusively isoprene units
(C) The lack of any functional groups
(D) A strict reliance on fatty acid biosynthesis

2016

139. Identify the INCORRECT statement regarding the arachidonic acid cascade.
(A) Arachidonic acid is released from membrane phospholipids by Phospholipase A2.
(B) Cyclooxygenase (COX) converts arachidonic acid to prostaglandins.
(C) The pathway relies entirely on the degradation of structural cellular proteins.
(D) Lipoxygenase converts arachidonic acid to leukotrienes.

2023

140. Determine the correct order of events in a typical adaptive immune response, then select the matching option.
I. Clonal expansion of specific lymphocytes
II. Antigen presentation by macrophages or dendritic cells
III. Elimination of the pathogen
IV. Recognition of the antigen by T-cells
(A) II, IV, I, III
(B) I, II, III, IV
(C) IV, I, II, III
(D) II, I, IV, III

2025

141. Which physical parameter is measured in a differential centrifugation experiment?
(A) The exact molecular weight of the organelle
(B) The sedimentation coefficient, primarily dependent on size and density
(C) The specific heat capacity of the organelle
(D) The enzymatic activity of the fraction

2015

142. Which thermodynamic relationship is correctly stated?
(A) $\Delta G = \Delta H - T\Delta S$
(B) $\Delta H = \Delta G - T\Delta S$
(C) $\Delta S = \Delta H - T\Delta G$
(D) $\Delta G = T\Delta S - \Delta H$

NODIA

2008

143. Identify the correct pair representing a cell organelle and its defining marker enzyme.
(A) Mitochondria - Glucose-6-phosphatase
(B) Lysosome - Acid phosphatase
(C) Peroxisome - Succinate dehydrogenase
(D) Endoplasmic Reticulum - Catalase

2002

144. Which process most appropriately describes the biological role of the Nernst equation?
(A) Determining the resting membrane potential created by ion gradients
(B) Calculating the standard free energy of ATP hydrolysis
(C) Determining the buffering capacity of blood
(D) Estimating the rate of enzymatic catalysis

2025

145. What structural feature allows thioesters to act as high-energy intermediates compared to typical oxygen esters?
(A) Thioesters exhibit less resonance stabilization than oxygen esters, making their hydrolysis more exergonic.
(B) Thioesters are inherently more stable and resist hydrolysis.
(C) Thioesters contain strong triple bonds.
(D) Thioesters form exceptionally strong hydrogen bonds with water.

2016

146. Which characteristic of the lipid bilayer explains membrane asymmetry?
(A) Lateral diffusion occurs much slower than transverse diffusion events.
(B) Lipid species are covalently cross-linked between the two leaflets.
(C) Membrane lipids are synthesized simultaneously on both bilayer sides.
(D) Transverse diffusion of lipids is slow without enzyme help.

2009

147. Eliminate the INCORRECT statement regarding primary and secondary active transport.
(A) Both require specific transport proteins.
(B) Both can move molecules against their concentration gradient.
(C) Secondary active transport depends on a gradient established by primary transport.
(D) Both rely directly on the continuous hydrolysis of ATP by the transport protein itself.

2009

148. Which term best classifies D-erythrose and D-threose, which are diastereomers that differ at exactly one chiral center?
(A) Enantiomers
(B) Epimers
(C) Anomers
(D) Conformational isomers

2015

149. Which of the following is NOT an accurate description of cellulose?
(A) It consists of D-glucose units.
(B) It contains $\beta(1_{\rightarrow}4)$ glycosidic linkages.
(C) It provides structural support in plant cell walls.
(D) It is a highly branched polysaccharide.

2018

150. What determines the exact isoelectric point (pI) of an acidic amino acid like glutamate?
(A) The average of the pKa values of the alpha-carboxyl and alpha-amino groups
(B) The average of the pKa values of the two carboxyl groups
(C) The pKa of the amino group alone
(D) The average of all three pKa values

2016

151. Which factor strictly limits the possible conformations in a Ramachandran plot?
(A) Steric hindrance between atoms in the polypeptide backbone and side chains
(B) Electrostatic attraction
(C) The formation of disulfide bonds
(D) The size of the solvent molecules

2006

152. In relation to protein folding, what does a protein domain represent?
(A) Sequence of three amino acids
(B) An independently folding structural and functional unit of a polypeptide
(C) The specific site where a cofactor binds
(D) The entire quaternary structure of an oligomeric protein

2009

153. Based on their melting points, which state of matter would a highly saturated fat likely occupy at room temperature?
(A) Gas
(B) Liquid
(C) Solid
(D) Plasma

2003

154. Identify the INCORRECT statement regarding cholesterol.
(A) It restricts the motion of fatty acid tails at high temperatures.
(B) It modulates membrane fluidity in animal cells.
(C) It is a precursor for steroid hormones.
(D) It contains a highly polar, large hydrophilic head group.

2007

155. Which pair correctly identifies the complementary base pairing in standard B-DNA?
(A) $A = T$ and $G \equiv C$
(B) $A = C$ and $G \equiv T$
(C) $A \equiv T$ and $G = C$
(D) $A = U$ and $G \equiv C$

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2018

156. Which of the following features is most appropriate for identifying tRNA molecules?
(A) A 5' cap and a 3' poly-A tail
(B) The presence of an anticodon loop and an amino acid acceptor stem
(C) Being the largest RNA species in the cell by mass
(D) Containing strictly standard A, U, G, C bases without modifications

2007

157. Which chemical classification encompasses plant secondary metabolites like menthol, camphor, and carotenoids?
(A) Alkaloids
(B) Phenolics
(C) Flavonoids
(D) Terpenoids

2010

158. What is the direct consequence of inhibiting the cyclooxygenase (COX) enzyme in animal tissues?
(A) Increased production of leukotrienes
(B) Decreased synthesis of prostaglandins and thromboxanes
(C) Accelerated breakdown of cell membranes
(D) Enhanced ATP synthesis

2018

159. Which class of immunoglobulin is capable of crossing the mammalian placenta to provide passive immunity to the fetus?
(A) IgG
(B) IgA
(C) IgM
(D) IgE

2012

160. Which type of non-covalent bond is highly directional and primarily responsible for the specific base-pairing in DNA?
(A) Van der Waals interactions
(B) Ionic bonds
(C) Hydrophobic interactions
(D) Hydrogen bonds

2003

161. Based on the Henderson-Hasselbalch equation, what happens if the concentration of the weak acid exceeds the concentration of the conjugate base?
(A) The pH is less than the pKa.
(B) The pH is greater than the pKa.
(C) The pH equals the pKa.
(D) The buffer completely fails.

2002

162. Eliminate the INCORRECT difference between eukaryotic and prokaryotic cells.
(A) Eukaryotes have linear chromosomes; prokaryotes generally have circular chromosomes.
(B) Eukaryotes compartmentalize functions in organelles; prokaryotes largely do not.
(C) Eukaryotes lack plasma membranes entirely, relying solely on cell walls.
(D) Eukaryotic ribosomes are 80S; prokaryotic ribosomes are 70S.

2022

163. Which morphological classification applies to the T4 bacteriophage?
(A) Icosahedral only
(B) Helical only
(C) Complex (head-tail morphology)
(D) Enveloped spherical

2002

164. What is the defining biochemical function of a plant vacuole?
(A) Acts as the primary site for light-dependent photosynthesis.
(B) Serves as the major location for ribosome subunit assembly.
(C) Generates cellular ATP via regulated oxidative phosphorylation.
(D) Nutrient storage, waste degradation, and turgor maintenance.

NODIA

2009

165. During differential centrifugation, what typically constitutes the final supernatant after ultracentrifugation at 100,000 x g?
(A) Cytosolic fraction (soluble proteins and molecules)
(B) Intact whole cells
(C) Nuclei
(D) Mitochondria and lysosomes

2003

166. Identify the correct statement about the calculation of standard free energy changes in coupled reactions.
(A) They cannot be calculated.
(B) The overall ΔG° is always zero.
(C) Coupled reactions must always share the same enzyme.
(D) The overall ΔG° is the arithmetic sum of the ΔG° of individual steps.

2025

167. Which of the following correctly pairs a reduced electron carrier with its typical metabolic role?
(A) NADH - Primarily used in reductive biosynthesis
(B) NADPH - Primarily provides electrons for the electron transport chain
(C) FADH2 - Donates electrons directly to Complex II of the respiratory chain
(D) NAD+ - Functions exclusively in the cytoplasm

2022

168. Why is ATP considered a "high-energy" compound?
(A) It contains highly stable covalent carbon-to-carbon chemical bonds.
(B) It remains resistant to all forms of enzymatic degradation.
(C) It possesses a highly nonpolar structure in aqueous environments.
(D) Hydrolysis relieves repulsion between negative phosphate groups.

2018

169. Identify the INCORRECT statement regarding the fluid mosaic model.
(A) Integral proteins - Spanning the lipid bilayer
(B) Peripheral proteins - Loosely attached to the membrane surface
(C) Glycolipids - Facing the intracellular cytosol
(D) Cholesterol - Modulating membrane fluidity

2008

170. Which mechanism allows an ionophore like valinomycin to transport potassium ions?
(A) It forms a stable covalent bond with the potassium ion.
(B) It masks the ion's charge with a hydrophobic outer surface.
(C) It functions as a primary active transmembrane pump.
(D) It disrupts the integrity of the lipid bilayer structure.

2016

171. Which functional group is unique to ketoses compared to aldoses?
(A) An internal carbonyl group (ketone)
(B) A terminal aldehyde group
(C) Multiple hydroxyl groups
(D) A carboxyl group

2022

172. Which term describes the polysaccharide hemicellulose?
(A) A homopolysaccharide made exclusively of glucose
(B) A strictly linear storage polymer
(C) An animal storage carbohydrate
(D) A heteropolysaccharide present in plant cell walls

2008

173. Which standard proteinogenic amino acid contains a sulfur atom but cannot form disulfide bridges?
(A) Cysteine
(B) Methionine
(C) Serine
(D) Threonine

2014

174. In a Ramachandran plot, what do the heavily clustered regions indicate?
(A) Conformations corresponding to common secondary structures like alpha-helices and beta-sheets
(B) Angles that result in severe steric clashes
(C) Regions only accessible to proline
(D) Angles defining the tertiary folding pathway

2002

175. Which force drives the quaternary assembly of most multi-subunit proteins in an aqueous environment?
(A) Extensive covalent cross-linking
(B) Strong repulsion between subunits
(C) The rigid binding of water molecules
(D) Hydrophobic interactions occurring at the subunit interfaces

2009

176. Identify the correct physical property comparison between unsaturated and saturated fatty acids.
(A) Unsaturated fatty acids are generally solids at room temperature.
(B) Unsaturated fatty acids pack more tightly than saturated ones.
(C) Saturated fatty acids have higher melting points due to greater van der Waals interactions.
(D) Saturated fatty acids are more susceptible to autoxidation.

2016

177. Which lipid class relies on a backbone of sphingosine rather than glycerol?
(A) Triacylglycerols
(B) Phosphatidic acid
(C) Cardiolipin
(D) Ceramides

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2025

178. What determines the structural distinction between A-DNA and B-DNA?
(A) A-DNA has a left-handed helix, while B-DNA is right-handed.
(B) A-DNA is wider and more compressed than B-DNA.
(C) A-DNA contains uracil in place of thymine residues.
(D) A-DNA is single-stranded, whereas B-DNA is double-stranded.

2012

179. Eliminate the INCORRECT statement regarding ribozymes.
(A) They are RNA molecules possessing catalytic activity.
(B) They can catalyze peptide bond formation in the ribosome.
(C) They are purely composed of protein.
(D) They play a role in RNA splicing.

2014

180. Which ecological function is most closely associated with plant secondary metabolites?
(A) Driving the primary reactions of photosynthesis
(B) Mediating interactions with the environment, such as defense and attraction
(C) Storing maximum energy for long-term survival
(D) Forming the structural backbone of the plant cell wall

2017

181. Which signaling role is typically NOT associated with eicosanoids?
(A) Regulation of blood pressure
(B) Induction of fever and inflammation
(C) Modulation of blood clotting
(D) Long-term maintenance of bone density

2023

182. Which cell type is defined by its ability to engulf large particulate matter or pathogens as a primary component of innate immunity?
(A) B-lymphocyte
(B) Macrophage
(C) T-lymphocyte
(D) Erythrocyte

2023

183. Identify the correct pair concerning molecular interactions.
(A) Van der Waals forces - Covalent bond sharing
(B) Ionic interactions - Electrostatic attraction between fully charged groups
(C) Hydrogen bonds - Strictly dependent on carbon atoms
(D) Hydrophobic effect - Driven by increasing enthalpy

2021

184. Which physiological buffer system operates primarily in the intracellular fluid space?
(A) Bicarbonate buffer
(B) Ammonia buffer
(C) Citrate buffer
(D) Phosphate buffer

2015

185. Which definition best suits a prokaryotic nucleoid?
(A) A membrane-bound organelle containing the genomic DNA.
(B) A specialized structure dedicated to protein synthesis.
(C) A storage granule for polyphosphate and energy reserves.
(D) The cell region where the genetic material is localized.

2016

186. Identify the INCORRECT statement regarding the replication cycle of viruses.
(A) Penetration involves the entry of viral genetic material into the host.
(B) Uncoating is always required for bacteriophages.
(C) Biosynthesis relies heavily on the host cell machinery.
(D) Release can occur via cell lysis or budding.

2013

187. Which process represents a defining function of the smooth endoplasmic reticulum?
(A) Synthesis of secreted proteins
(B) Synthesis of complex lipids and detoxification of xenobiotics
(C) Generation of ATP
(D) Degradation of obsolete organelles

2006

188. What is the fundamental principle behind density gradient centrifugation?
(A) Particles are separated solely based on how long the centrifuge spins.
(B) Particles move through a gradient until they reach a position where their density matches that of the surrounding medium.
(C) Particles bind to specific antibodies attached to the tube wall.

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(D) Particles are heated to different temperatures.

2005

189. According to the Second Law of Thermodynamics, what happens to the entropy of the universe during any spontaneous process?
(A) It increases.
(B) It remains constant.
(C) It decreases.
(D) It fluctuates randomly.

2017

190. Which of the following defines the relationship in the Nernst equation?
(A) It relates the equilibrium potential of an ion to its concentration gradient across a membrane.
(B) It relates the standard free energy to the equilibrium constant.
(C) It defines the rate of enzymatic reactions.
(D) It calculates the osmotic pressure of a cell.

2007

191. Which compound acts as the central intermediate integrating metabolism due to its high phosphoryl-transfer potential?
(A) Glucose-6-phosphate
(B) Adenosine triphosphate (ATP)
(C) Pyruvate
(D) Nicotinamide adenine dinucleotide

2002

192. Which characteristic of the lipid bilayer is described by the "mosaic" part of the fluid mosaic model?
(A) The solid arrangement of rigid lipids
(B) The diverse array of integral and peripheral proteins embedded in or attached to the membrane
(C) The symmetrical distribution of phospholipids
(D) The pure carbohydrate nature of the membrane

2010

193. How does facilitated diffusion differ from simple diffusion?
(A) It transports molecules faster but is subject to saturation (V_{max}) at high solute concentrations.
(B) It is strictly a non-saturable process.
(C) It requires ATP hydrolysis.
(D) It can only transport gases like O_2 and CO_2.

2014

194. Which carbon is designated as the anomeric carbon in an aldohexose ring?
(A) C-1
(B) C-2
(C) C-5
(D) C-6

2014

195. Which of the following identifies a strictly animal storage polysaccharide?
(A) Glycogen
(B) Amylose
(C) Cellulose
(D) Hemicellulose

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2025

196. Which standard amino acid has an R-group with a pKa closest to physiological pH, allowing it to act as an effective buffer at pH 7.4?
(A) Lysine
(B) Histidine
(C) Arginine
(D) Glutamate

2002

197. Which type of bonding stabilizes secondary structures like alpha helices and beta sheets?
(A) Hydrophobic interactions between side chains
(B) Hydrogen bonding between backbone amide and carbonyl groups
(C) Covalent disulfide bonds
(D) Ionic bonds between charged side chains

2011

198. Eliminate the INCORRECT statement regarding protein denaturation.
(A) It does not break the primary sequence of amino acids.
(B) It can be induced by urea or guanidinium chloride.
(C) It is a completely irreversible process in all proteins.
(D) It disrupts the functional 3D conformation.

2016

199. Which physical property indicates that a fatty acid is unsaturated?
(A) It has a higher melting point than its saturated counterpart.
(B) It possesses one or more carbon-carbon double bonds in its chain.
(C) It is entirely solid at room temperature.
(D) It has a straight, unbent hydrocarbon chain.

2010

200. What role do sterols, such as cholesterol, play in eukaryotic biological membranes?
(A) They act as bidirectional regulators of membrane fluidity.
(B) They serve as the primary source of cellular ATP.
(C) They are exclusively responsible for active transport.
(D) They prevent all lateral movement of membrane proteins.

2019

201. Which term describes the sequence-specific localized variations in B-DNA structure?
(A) Base-pair roll, tilt, and twist
(B) Z-DNA transitions
(C) DNA supercoiling
(D) Chromatin remodeling

2007

202. What is the fundamental difference between mRNA and rRNA?
(A) mRNA carries coding information to the ribosome; rRNA is a structural and catalytic component of the ribosome.
(B) mRNA is catalytic; rRNA provides only sequence information.
(C) mRNA is double-stranded; rRNA is single-stranded.
(D) mRNA is permanent; rRNA is rapidly degraded after translation.

2022

203. Which class of secondary metabolites includes defensive compounds structurally characterized by multiple phenol units?
(A) Tannins (Phenolics)
(B) Alkaloids
(C) Steroids
(D) Monoterpenes

2019

204. Which structural feature defines arachidonic acid?
(A) 16 carbons, 0 double bonds
(B) 18 carbons, 2 double bonds
(C) 20 carbons, 4 double bonds
(D) 22 carbons, 6 double bonds

2009

205. Which region of an immunoglobulin molecule determines its specific binding affinity for an antigen?
(A) The constant region (Fc)
(B) The variable regions (Fab) of the heavy and light chains
(C) The hinge region
(D) The disulfide bridges

2011

206. Which force primarily limits the close approach of atoms to establish their optimal van der Waals contact distance?
(A) Steric repulsion between electron clouds
(B) Electrostatic attraction
(C) Hydrogen bonding
(D) The hydrophobic effect

2014

207. What physiological change would cause the pH of blood to decrease according to the Henderson-Hasselbalch framework for the bicarbonate buffer system?
(A) An increase in bicarbonate concentration
(B) An increase in dissolved CO_2 (pCO_2)
(C) A decrease in dissolved CO_2 (pCO_2)
(D) Hyperventilation

2003

208. Identify the correct functional difference between eukaryotic mitochondria and chloroplasts.
(A) Mitochondria produce glucose; chloroplasts degrade glucose.
(B) Mitochondria perform cellular respiration; chloroplasts perform photosynthesis.
(C) Mitochondria possess DNA; chloroplasts do not.
(D) Mitochondria lack a double membrane; chloroplasts possess one.

2008

209. Eliminate the INCORRECT pair defining virus structural terms.
(A) Capsid - Protein coat enclosing the viral genome
(B) Capsomere - Individual protein subunit of the capsid
(C) Envelope - Lipid bilayer derived from the host cell
(D) Prophage - A virion actively releasing from a cell

2025

210. Which sub-compartment of the mitochondria contains the enzymes of the citric acid cycle?
(A) Outer membrane
(B) Mitochondrial matrix
(C) Intermembrane space
(D) Inner membrane

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2005

211. Which method is most effective for separating organelles with identical sizes but different densities?
(A) Electrophoresis
(B) Differential centrifugation
(C) Isopycnic density gradient centrifugation
(D) Chromatography

2013

212. In a biological system, what does a negative ΔG signify about a reaction?
(A) It requires an input of energy to proceed.
(B) It is thermodynamically favorable (spontaneous).
(C) It proceeds at an extremely rapid rate.
(D) It has reached equilibrium.

2024

213. Which definition best suits a standard reduction potential (E°)?
(A) The tendency of a chemical species to be reduced, measured under standard conditions
(B) The total energy available for work in a system
(C) The speed of an oxidation reaction
(D) The required activation energy for an electron transfer

2012

214. Which structural feature of ATP is most directly responsible for its high phosphoryl group transfer potential?
(A) The chain of three phosphate groups linked by phosphoanhydride bonds
(B) The adenine base
(C) The ribose sugar
(D) The glycosidic linkage

2024

215. Which of the following identifies a correct physical consequence of decreasing the temperature of a biological membrane?
(A) The membrane becomes more fluid.
(B) The rate of lateral diffusion increases.
(C) The membrane tends to transition to a more rigid, gel-like state.
(D) Integral proteins spontaneously detach.

2016

216. Which physiological mechanism exemplifies secondary active transport?
(A) The Na+/K+ ATPase pump in plasma membranes.
(B) Aquaporin proteins transporting water molecules.
(C) The passive diffusion of oxygen into the cell.
(D) The glucose-Na+ symporter system in the intestinal epithelium.

2012

217. Identify the correct stereochemical designation for a monosaccharide with the hydroxyl group on the chiral carbon furthest from the carbonyl group pointing to the right in a Fischer projection.
(A) D-isomer
(B) L-isomer
(C) Alpha-anomer
(D) Beta-anomer

2004

218. Which statement correctly differentiates starch and cellulose?
(A) Starch is composed of L-glucose; cellulose is composed of D-glucose.
(B) Starch contains α-glycosidic bonds; cellulose contains β-glycosidic bonds.
(C) Starch is a structural component; cellulose is a storage component.
(D) Starch is unbranched; cellulose is highly branched.

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2009

219. Eliminate the INCORRECT property of an amino acid at its isoelectric point (pI).
(A) It is predominantly in the zwitterionic form.
(B) It has a net electrical charge of zero.
(C) It does not migrate in an electric field.
(D) It is highly soluble in non-polar solvents.

2023

220. Which secondary structure motif often connects antiparallel beta-strands?
(A) Beta-turn
(B) Alpha-helix
(C) Coiled-coil
(D) Leucine zipper

2025

221. Which thermodynamic concept best describes the unfolding of a protein when heated?
(A) Enthalpy-driven, due to the breaking of non-covalent bonds
(B) Entropy-driven, due to the increased conformational freedom of the polypeptide chain
(C) Highly exergonic
(D) Irreversible under all conditions

2004

222. What dictates the numbering of carbons in the delta (Δ) nomenclature of fatty acids?

(A) Numbering starts from the carboxyl carbon as C-1.
(B) Numbering starts from the methyl end.
(C) Numbering starts from the first double bond.
(D) Numbering starts from the omega carbon.

2006

223. Which basic structure forms the core of a glycerophospholipid?
(A) sn-glycerol-3-phosphate
(B) Sphingosine
(C) Cholesterol
(D) Isoprene

2004

224. Which form of DNA is favored in a dehydrated environment and has an 11-bp per turn right-handed helix?
(A) A-DNA
(B) B-DNA
(C) Z-DNA
(D) Circular DNA

2023

225. Which RNA species contains an unusual modified base known as pseudouridine (Ψ)?
(A) mRNA
(B) tRNA
(C) 5S rRNA
(D) miRNA

2022

226. Which of the following is an established physiological role of plant alkaloids?
(A) Deterrence against herbivores and pathogens due to their toxicity
(B) Primary electron donors in photosynthesis
(C) Structural reinforcement of the stem
(D) Formation of the lipid bilayer

2004

227. Identify the correct pair regarding eicosanoid structural origins.
(A) Prostaglandins - Derived from linear 16-carbon acids
(B) Leukotrienes - Contain a five-membered carbon ring
(C) Prostaglandins - Contain a five-membered carbon ring derived from arachidonic acid
(D) Thromboxanes - Derived from cholesterol

2014

228. Which type of immune cell is primarily responsible for orchestrating the overall immune response by releasing cytokines?
(A) Helper T-cells ($CD4^+$)
(B) Cytotoxic T-cells ($CD8^+$)
(C) Plasma cells
(D) Erythrocytes

2005

229. Which biochemical principle explains why oil and water do not mix?
(A) High affinity of oil for hydrogen bonds
(B) The hydrophobic effect driven by water entropy
(C) Ionic repulsion
(D) Covalent bonding between oil molecules

2009

230. Which mathematical relationship is central to the Henderson-Hasselbalch equation?
(A) Logarithm of the ratio of conjugate base to weak acid
(B) Square root of the acid concentration
(C) Exponential decay of pH
(D) Linear sum of pKa and acid concentration

2016

231. Which feature specifically allows eukaryotic cells to compartmentalize competing metabolic processes?
(A) Presence of ribosomes
(B) Membrane-bound organelles
(C) Cytoskeleton
(D) Flagella

2011

232. Eliminate the INCORRECT statement regarding bacteriophages.
(A) They are viruses that strictly infect bacteria.
(B) They can enter a state called lysogeny.
(C) They commonly possess a lipid envelope derived from the bacterial host membrane.
(D) They inject their nucleic acid into the host cell, leaving the capsid outside.

2022

233. Which organelle is recognized as the major site of degradation for extracellular macromolecules and obsolete cellular components?
(A) Lysosome
(B) Peroxisome
(C) Smooth ER
(D) Nucleolus

2002

234. What is the fundamental utility of marker enzymes in subcellular fractionation?
(A) They identity the purity and presence of specific organelle fractions.
(B) They increase the rate of centrifugation.

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(C) They break down the cell wall before centrifugation.
(D) They stain the organelles for electron microscopy.

2003

235. Which thermodynamic variable is most appropriate to determine whether a reaction will proceed spontaneously at a given temperature and pressure?
(A) Enthalpy (ΔH)
(B) Entropy (ΔS)
(C) Gibbs Free Energy (ΔG)
(D) Activation energy

2002

236. Which parameter directly determines the standard reduction potential of a redox couple?
(A) Its affinity for electrons relative to a standard hydrogen electrode
(B) Its concentration
(C) The presence of an enzyme catalyst
(D) Its molecular weight

2022

237. Which statement correctly identifies a thermodynamic coupling in metabolism?
(A) Hydrolysis of ATP is coupled to an endergonic reaction to make the overall process exergonic.
(B) Synthesis of ATP is directly coupled to the synthesis of proteins without intermediates.
(C) Two exergonic reactions are coupled to produce heat.
(D) An exergonic reaction is coupled to another exergonic reaction to stop the process.

2022

238. Which property of a membrane is primarily dictated by its lipid composition?
(A) The exact sequence of proteins present
(B) Its overall fluidity and thickness
(C) Its ability to perform oxidative phosphorylation
(D) The size of the cell

2019

239. Which biological scenario describes a primary active transport process?
(A) Movement of glucose into an erythrocyte via GLUT1
(B) Movement of water through aquaporins
(C) Movement of Ca^{2+} out of the cytosol into the sarcoplasmic reticulum via the SERCA pump
(D) Efflux of K^+ through leak channels

2022

240. Which specific reaction defines mutarotation in a glucose solution?
(A) The interconversion between alpha-D-glucopyranose and beta-D-glucopyranose
(B) The conversion of D-glucose to L-glucose
(C) The conversion of glucose to fructose
(D) The breakdown of glucose into pyruvate

2017

241. Which class of molecules provides the most structural rigidity to plant cell walls through long, crystalline chains?
(A) Cellulose
(B) Starch
(C) Glycogen
(D) Pectin

2015

242. Eliminate the INCORRECT statement about the isoelectric point (pI).
(A) At the pI, the net charge of the molecule is zero.
(B) At the pI, amino acids exhibit their lowest solubility in water.
(C) At the pI, the molecule is uncharged and lacks any ionized groups.
(D) The pI is determined by the pKa values of the ionizable groups.

2004

243. Which structural element is characterized by a tightly coiled backbone with side chains extending outward?
(A) Alpha-helix
(B) Beta-sheet
(C) Beta-turn
(D) Random coil

2021

244. Which organizational level refers to the specific arrangement of multiple distinct folded polypeptide chains into a single functional complex?
(A) Primary structure
(B) Secondary structure
(C) Tertiary structure
(D) Quaternary structure

2011

245. Identify the correct relationship between fatty acid structure and its melting point.
(A) Increasing chain length increases melting point, while increasing unsaturation decreases it.
(B) Increasing chain length decreases melting

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point.
(C) Increasing unsaturation (double bonds) increases melting point.
(D) Neither chain length nor unsaturation affects melting point.

2010

246. Which structural backbone differentiates a sphingolipid from a triacylglycerol?
(A) Triacylglycerols have a cholesterol backbone.
(B) Sphingolipids have a long-chain amino alcohol backbone.
(C) Sphingolipids lack fatty acid chains completely.
(D) Triacylglycerols contain a phosphate group.

2017

247. Which pair correctly describes the Watson-Crick B-DNA structure?
(A) 10.5 base pairs per turn; anti-parallel strands
(B) 12 base pairs per turn; parallel strands
(C) 11 base pairs per turn; left-handed helix
(D) 10.5 base pairs per turn; single-stranded

2023

248. Which RNA serves as the direct template for translation into a polypeptide?
(A) mRNA
(B) rRNA
(C) snRNA
(D) tRNA

2002

249. Which class of plant secondary metabolites includes nitrogen-containing compounds that are synthesized from amino acids and release toxic hydrogen cyanide when the plant is damaged?
(A) Alkaloids
(B) Cyanogenic glycosides
(C) Terpenoids
(D) Glucosinolates

2021

250. Which physiological response is a direct consequence of prostaglandin signaling?
(A) Mediation of localized inflammatory responses
(B) Immediate increase in heart rate akin to adrenaline
(C) Storage of fat in adipose tissue
(D) Direct destruction of invading bacteria

2017

251. Which statement best defines the function of macrophages in the immune system?
(A) They act primarily as phagocytes and antigen-presenting cells.
(B) They produce highly specific circulating antibodies.
(C) They are the primary cells that form memory B-cells.
(D) They strictly attack cells marked by CD^{8+} T-cells.

2007

252. Which type of non-covalent bond relies on the fluctuating electron clouds of closely situated atoms?
(A) Van der Waals forces
(B) Hydrogen bonds
(C) Ionic bonds
(D) Hydrophobic interactions

2012

253. Which of the following defines a buffer's capacity?
(A) Its ability to resist changes in pH upon the addition of a strong acid or base
(B) Its absolute pH value
(C) Its total concentration of water
(D) Its standard free energy

2025

254. Eliminate the INCORRECT statement regarding eukaryotic compartmentalization.
(A) It allows spatial separation of incompatible biochemical reactions.
(B) It ensures that all enzymes are exposed to identical pH environments.
(C) It concentrates enzymes and substrates to enhance reaction rates.
(D) It provides local microenvironments tailored to specific metabolic functions.

2013

255. Which phase of a viral replication cycle involves the assembly of newly synthesized viral genomes and capsids?
(A) Attachment
(B) Penetration
(C) Maturation (Assembly)
(D) Uncoating

2019

256. Which cellular structure strictly orchestrates the sorting and packaging of newly synthesized proteins for secretion?
(A) Golgi apparatus
(B) Mitochondria
(C) Lysosomes
(D) Nucleus

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2014

257. Which fraction sediments last during a standard differential centrifugation of cell homogenates?
(A) Nuclear fraction
(B) Mitochondrial fraction
(C) Microsomal fraction
(D) Cytosolic (soluble) fraction

2022

258. Which thermodynamic state is indicated by a standard free energy change (ΔG°) of zero?
(A) The reaction is highly exergonic.
(B) The reaction is highly endergonic.
(C) The reaction is at equilibrium under standard conditions.
(D) The reaction is non-spontaneous in all directions.

2024

259. Identify the correct pair defining a redox parameter.
(A) E° - Standard reduction potential
(B) NAD^{+} - Fully reduced form
(C) $FADH_2$ - Fully oxidized form
(D) ΔG° - Standard reduction potential

2012

260. Which chemical characteristic of the thioester bond in acetyl-CoA accounts for its role as a high-energy intermediate?
(A) Its inability to be hydrolyzed
(B) Its lack of resonance stabilization relative to oxygen esters
(C) Its unusually strong carbon-sulfur covalent bond
(D) Its highly polar nature in lipid environments

2014

261. Which structural component maintains the fluidity of biological membranes at low temperatures in animal cells?
(A) Saturated fatty acids
(B) Cholesterol
(C) Integral proteins
(D) Peripheral proteins

2023

262. Which term describes a membrane protein that exclusively forms a pore to allow ions to flow down their electrochemical gradient without conformational changes linked to energy utilization?
(A) Channel
(B) Pump
(C) Symporter
(D) Antiporter

2009

263. Which term refers to isomers that differ in configuration only at the hemiacetal or hemiketal carbon?
(A) Anomers
(B) Enantiomers
(C) Epimers
(D) Diastereomers

2021

264. Which of the following represents a structural hetero-polysaccharide?
(A) Glycogen
(B) Peptidoglycan
(C) Amylose
(D) Cellulose

2010

265. Which of the following standard amino acids is classified as basic due to its positively charged side chain at neutral pH?
(A) Lysine
(B) Glutamate
(C) Serine
(D) Valine

2004

266. Identify the INCORRECT statement regarding the Ramachandran plot.
(A) It maps the allowed phi and psi backbone dihedral angles.
(B) It maps the rotation of the peptide bond itself.
(C) White or blank areas represent sterically disallowed conformations.
(D) Different secondary structures fall into specific predicted regions.

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2015

267. Which process is strictly an example of protein denaturation?
(A) Loss of three-dimensional structure due to exposure to high heat
(B) Cleavage of a polypeptide into smaller peptides by a protease
(C) Association of two alpha-helices into a coiled-coil
(D) Addition of a phosphate group to a serine residue

2002

268. Which fatty acid is typically represented by the nomenclature 18:2(9,12)?
(A) Linoleic acid
(B) Oleic acid
(C) Stearic acid

(D) Arachidonic acid

2019

269. Which type of lipid relies primarily on a tetracyclic hydrocarbon structure?
(A) Sterols
(B) Glycerophospholipids
(C) Sphingolipids
(D) Waxes

2014

270. Which specific interaction is responsible for the higher melting temperature of DNA rich in GC base pairs compared to AT-rich DNA?
(A) GC pairs have three hydrogen bonds and strong stacking.
(B) GC pairs form covalent bonds between the two strands.
(C) GC pairs are found exclusively in A-DNA structures.
(D) GC pairs completely exclude all local water molecules.

2003

271. Which RNA structure is defined by its ability to undergo self-splicing without protein enzymes?
(A) Ribozyme
(B) mRNA
(C) tRNA
(D) 16S rRNA

2025

272. Which of the following best describes the structural origin of phenolic compounds in plants?
(A) They contain an aromatic ring bearing one or more hydroxyl groups.
(B) They are synthesized entirely from isoprene units.
(C) They are simple chains of amino acids.
(D) They are derived purely from nucleotide degradation.

2023

273. Which of the following is an immediate product of the cyclooxygenase pathway acting on arachidonic acid?
(A) Prostaglandin H_2
(B) Leukotriene A_4
(C) Cholesterol
(D) Phosphatidylinositol

2002

274. Eliminate the INCORRECT statement regarding immunoglobulins.
(A) They are synthesized by T-cells.
(B) They are composed of two heavy and two light chains.
(C) They contain both constant and variable domains.
(D) They are stabilized by disulfide bonds.

2016

275. Which weak interaction is entropy-driven and critical for micelle formation by amphipathic molecules?
(A) Hydrophobic effect
(B) Hydrogen bonding
(C) Electrostatic interaction
(D) Disulfide bond formation

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2013

276. Which condition applies when a buffer is most effective at maintaining a stable pH?
(A) When pH is exactly equal to the pKa of the weak acid
(B) When pH equals pKa + 2
(C) When the weak acid is completely dissociated
(D) When the conjugate base is completely neutralized

2005

277. Which structure is a distinguishing feature of eukaryotic cell organization?
(A) The presence of a highly organized cytoskeleton
(B) The nucleoid region
(C) The lack of internal membrane systems
(D) The exclusive use of RNA as genetic material

2017

278. Which statement correctly identifies a unique aspect of retroviral replication?
(A) They utilize reverse transcriptase to convert their RNA genome into DNA.
(B) They strictly use double-stranded DNA as their infective genome.
(C) They only infect plant cells.
(D) They never integrate into the host genome.

2010

279. Which organelle is characterized by containing extensive stacks of flattened thylakoid membranes?
(A) Chloroplast
(B) Mitochondrion
(C) Endoplasmic reticulum
(D) Golgi complex

2013

280. Which of the following enzymes is commonly used as a biochemical marker for the identification of peroxisomes during cell fractionation?
(A) Catalase
(B) Acid phosphatase
(C) Succinate dehydrogenase
(D) DNA polymerase

2025

281. According to the Third Law of Thermodynamics, what is the value of the entropy of a perfectly crystalline substance at absolute zero (0 K)?
(A) Zero
(B) Infinite
(C) 1.0 cal/mol·K
(D) Equal to the enthalpy of the system

2014

282. Which statement correctly explains why oxygen is an excellent final electron acceptor in cellular respiration?
(A) It has a highly positive standard reduction potential, signifying a high affinity for electrons.
(B) It has a highly negative standard reduction potential.
(C) It forms weak covalent bonds with carbon.
(D) It does not require an enzyme to accept electrons.

2017

283. Which high-energy bond is found in coenzyme A when it is attached to an acetyl group?
(A) Thioester bond
(B) Phosphodiester bond
(C) Phosphoanhydride bond
(D) Peptide bond

2001

284. Which movement of lipids in a biomembrane occurs most rapidly and frequently?
(A) Lateral diffusion within a single leaflet
(B) Transverse diffusion (flip-flop)
(C) Complete extraction into the aqueous phase
(D) Covalent linking to adjacent lipids

2008

285. Which type of transport uses the downhill gradient of one ion to drive the uphill transport of another molecule?
(A) Secondary active transport
(B) Primary active transport
(C) Simple diffusion
(D) Facilitated diffusion via a uniporter

2022

286. Which characteristic identifies D-mannose in relation to D-glucose?
(A) It is a C-2 epimer of glucose.
(B) It is a C-4 epimer of glucose.
(C) It is an enantiomer of glucose.
(D) It is a ketose sugar.

2017

287. Which polysaccharide primarily constitutes the exoskeleton of arthropods?
(A) Chitin
(B) Cellulose
(C) Glycogen
(D) Starch

2005

288. Which of the following represents an amino acid with a nonpolar, aromatic side chain?
(A) Phenylalanine
(B) Glutamine
(C) Aspartate
(D) Arginine

2001

289. Which structural property is strictly associated with parallel beta-sheets?
(A) Strands run in the same N-to-C direction, leading to distorted, angled hydrogen bonds.
(B) Strands run in opposite N-to-C directions.
(C) They are exclusively found in membrane proteins.
(D) They cannot form in aqueous environments.

2019

290. Which process best defines the thermodynamics of protein folding?
(A) Spontaneous process driven by entropic gain of bulk water.
(B) Highly endothermic process requiring continuous ATP.
(C) Process resulting in maximum entropy for the chain.
(D) Folding process that is independent of temperature.

2007

291. Which specific physical state is expected for a fatty acid with multiple cis-double bonds at room temperature?
(A) Liquid
(B) Highly crystalline solid
(C) Gas
(D) Insoluble precipitate

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2007

292. Which lipid class is critical for determining blood group types due to their specific carbohydrate head groups?
(A) Sphingoglycolipids
(B) Triacylglycerols
(C) Cholesterol
(D) Phosphatidic acids

2001

293. Which structural parameter differentiates Z-DNA from B-DNA?
(A) Z-DNA is a left-handed helix with a zig-zag backbone; B-DNA is right-handed.
(B) Z-DNA lacks completely complementary base pairing.
(C) Z-DNA strictly contains uracil.
(D) Z-DNA is fundamentally single-stranded.

2007

294. Eliminate the INCORRECT statement regarding transfer RNA (tRNA).
(A) It adopt a 3D L-shaped structure.
(B) It contains an anticodon region that pairs with mRNA.
(C) It attaches amino acids at its 3' end.
(D) It is primarily responsible for forming the structural matrix of the nucleus.

2003

295. Which class of plant secondary metabolites is best known for containing nitrogen and having profound pharmacological effects on animals?
(A) Alkaloids
(B) Phenolics
(C) Flavonoids
(D) Terpenoids

2009

296. Which enzyme catalyzes the committed step in the synthesis of prostaglandins from arachidonic acid?
(A) Cyclooxygenase (COX)
(B) Lipoxygenase
(C) Phospholipase C
(D) Adenylate cyclase

2019

297. Which specific immune cell is targeted and progressively destroyed by the Human Immunodeficiency Virus (HIV)?
(A) Helper T-cell ($CD4^+$)
(B) B-lymphocyte
(C) Cytotoxic T-cell ($CD8^+$)
(D) Neutrophil

2009

298. Which thermodynamic factor largely drives the formation of the lipid bilayer in biological membranes?
(A) Maximization of solvent entropy via the hydrophobic effect
(B) Formation of covalent bonds between lipid tails
(C) Favorable enthalpy of interaction between hydrocarbon chains and water
(D) Decreased entropy of the entire system

2011

299. In biochemistry, a buffer is considered to have its maximum buffering capacity within which pH range?
(A) $pH = pKa \pm 1$
(B) $pH = pKa \pm 2$
(C) pH 1.0 to 7.0
(D) Always at pH 7.4

2022

300. Which final cellular structure is distinctly defined by possessing an inner membrane with extensive folds called cristae?
(A) Mitochondrion
(B) Chloroplast
(C) Golgi apparatus
(D) Nucleus

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NODIA

ANSWERS

1. (D) Hydrophobic effect
The stabilization of the DNA double helix core is primarily driven by the burial of nonpolar nitrogenous bases away from the aqueous environment. This phenomenon maximizes the entropy of surrounding water molecules by reducing ordered cage-like structures that form around hydrophobic surfaces. This provides a significant thermodynamic force for the folding and stability of the genetic material.

2. (C) 1:1
In a buffer system described by the Henderson-Hasselbalch equation, the relationship between pH and the concentrations of the conjugate base and weak acid is logarithmic. When the pH of the solution matches the acid dissociation constant of the weak acid, the concentrations of the ionized and unionized forms become equal, resulting in a ratio of exactly one to one.

3. (B) Membrane-bound nucleus
Eukaryotic cells are defined by complex internal compartmentalization, specifically the presence of a membrane-enclosed nucleus that houses the genetic material. In contrast, prokaryotic cells lack such internal membrane systems, and their DNA is localized within a nucleoid region. This fundamental structural difference allows for sophisticated regulation of gene expression and specialized metabolic processes within the eukaryotic cell environment.

4. (D) Prophages undergo continuous active replication independent of host division.
During the lytic cycle, a bacteriophage integrates its genome into the host chromosome as a prophage. Instead of replicating independently or destroying the cell, the viral DNA remains dormant and is replicated passively along with the bacterial genome during cell division. This allows the virus to persist within a population without immediately causing host cell lysis or active viral production.

5. (A) Modification, sorting, and packaging of proteins
The Golgi apparatus acts as the central processing hub of the eukaryotic endomembrane system. It receives proteins from the rough endoplasmic reticulum and subjects them to further modifications, such as glycosylation or phosphorylation. Subsequently, these molecules are sorted and packaged into specialized vesicles for transport to specific intracellular destinations or for secretion outside the cell through the plasma membrane.

6. (C) Nuclei
Subcellular fractionation separates organelles based on their size and density using varying centrifugal speeds. During differential centrifugation, the largest and densest components sediment first at the lowest gravitational forces. Consequently, the nuclei are the first organelles to form a pellet at low speeds, while smaller components like mitochondria and ribosomes require significantly higher speeds and longer durations to sediment.

7. (A) $\Delta G^{\circ} < 0$
A thermodynamically spontaneous reaction is characterized by a decrease in the Gibbs free energy of the system. Under standard conditions, a negative value for the change in free energy indicates that the process can occur without the input of external energy. This parameter reflects the balance between enthalpy and entropy changes, determining the inherent directionality of chemical reactions.

8. (D) It makes ΔG° negative, indicating a spontaneous reaction.
The relationship between standard reduction potential and free energy change is inversely proportional. A positive standard reduction potential indicates a strong tendency for a redox reaction to proceed as written. According to the governing thermodynamic equations, this positive potential results in a negative free energy change, which signifies that the overall reaction is spontaneous and releases energy for use.

9. (B) Phosphoanhydride bonds
Adenosine triphosphate contains two high-energy phosphoanhydride bonds between its phosphate groups. The hydrolysis of these specific linkages is highly exergonic because it

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relieves the significant electrostatic repulsion between the negatively charged oxygen atoms. The energy released during the breaking of these bonds is fundamental for driving various endergonic metabolic processes and active transport mechanisms within the living cell.

10. (B) I and III
Biological membranes are dynamic structures described by the fluid mosaic model, where phospholipids and proteins move laterally. Phospholipids frequently undergo rapid lateral diffusion, while transverse movement across the bilayer is slow and usually requires specific enzymes. Integral membrane proteins are deeply embedded within this hydrophobic environment, contributing to the selective permeability and diverse functional capacity of the cellular boundary.

11. (D) It uses electrochemical gradients established by a primary pump mechanism.
Secondary active transport mechanisms move solutes against their concentration gradients by utilizing the potential energy stored in electrochemical gradients. These gradients are initially generated by primary active transport systems that directly hydrolyze adenosine triphosphate. By coupling the downhill movement of one ion to the uphill transport of another molecule, cells can efficiently accumulate nutrients without consuming energy during every step.

12. (A) Epimers
Monosaccharides that differ in the spatial arrangement of atoms around only one specific chiral center are categorized as epimers. For instance, D-glucose and D-galactose share identical structures except for the configuration at the fourth carbon atom. This subtle structural variation is biochemically significant, as enzymes often exhibit high specificity for one epimer over the other during critical metabolic carbohydrate reactions.

13. (B) Glycogen - $\alpha(1 \rightarrow 4)$ and $\alpha(1 \rightarrow 6)$
Glycogen is the primary storage polysaccharide in animals and is highly branched for rapid mobilization. It consists of glucose units linked by alpha one-four glycosidic bonds in the linear chains, with alpha one-six linkages occurring at the branching points. This complex architecture allows multiple enzymes to work simultaneously, facilitating the quick release of glucose during periods of high metabolic demand.

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14. (B) Glycine
Glycine is unique among the twenty standard amino acids because its side chain consists only of a single hydrogen atom. Consequently, the alpha-carbon of glycine is bonded to two identical hydrogen atoms, making it achiral. This lack of a chiral center prevents the existence of stereoisomers, allowing glycine to reside in sterically restricted regions of protein structures without constraint.

15. (C) A is true but R is false.
The alpha-helix is a common protein secondary structure stabilized by intramolecular hydrogen bonds between the carbonyl oxygen and the amide hydrogen four residues apart. While proline is an amino acid, it is rarely found in the middle of these helices because its rigid cyclic structure and lack of an amide hydrogen act as a destabilizing helix breaker rather than enhancer.

16. (C) Disulfide bridges
Tertiary structure represents the overall three-dimensional folding of a single polypeptide chain. While this conformation is largely stabilized by non-covalent interactions like hydrogen bonds and hydrophobic forces, disulfide bridges are unique covalent bonds formed between the sulfhydryl groups of two cysteine residues. These strong linkages provide significant structural stability, especially in proteins that are secreted or function in harsh environments.

17. (D) Arachidonic acid
Polyunsaturated fatty acids contain two or more double bonds along their hydrocarbon chains. Arachidonic acid is a prominent example, featuring a twenty-carbon chain with four cis-double bonds. These double bonds introduce bends in the molecule, affecting membrane fluidity and serving as precursors for the synthesis of bioactive signaling molecules like prostaglandins, thromboxanes, and leukotrienes during various physiological and inflammatory processes.

18. (C) Cholesterol - Steroid nucleus
Cholesterol is an essential component of animal cell membranes and is characterized by a rigid four-ring steroid nucleus. This hydrophobic structure allows it to insert into the lipid

bilayer, where it modulates membrane fluidity and permeability. Beyond its structural role, cholesterol serves as the primary metabolic precursor for the synthesis of bile acids, vitamin D, and various essential steroid hormones.

19. (D) Z-DNA - Broadest helix diameter
DNA can adopt different structural conformations depending on sequence and environment. B-DNA is the standard right-handed helix found in cells, while A-DNA is a wider, dehydrated form. Z-DNA is a unique left-handed helix with a zig-zag backbone that is narrower and more elongated than the B-form. It is often favored by sequences with alternating purine and pyrimidine bases.

20. (C) I, II and III
Ribonucleic acids perform diverse and essential roles in protein synthesis and cellular regulation. Messenger RNA acts as the blueprint for translation, transfer RNA facilitates the delivery of specific amino acids, and ribosomal RNA provides the structural and catalytic framework of the ribosome. Unlike standard RNA, ribozymes possess enzymatic activity, demonstrating that nucleic acids can function as biological catalysts like proteins.

21. (C) Terpenoids
Terpenoids represent a vast class of plant secondary metabolites derived from five-carbon isoprene units. Their biosynthesis occurs through two distinct pathways: the mevalonate pathway in the cytosol and the non-mevalonate pathway in the plastids. These compounds serve diverse ecological functions, ranging from attracting pollinators with fragrant scents to protecting the plant from herbivory through the production of toxic or repellent substances.

22. (B) Cyclooxygenase
The cyclooxygenase enzyme plays a pivotal role in the arachidonic acid cascade by catalyzing the initial steps of prostaglandin synthesis. It converts the released fatty acid into unstable intermediates, which are subsequently transformed into various prostaglandins and thromboxanes. This pathway is a major target for non-steroidal anti-inflammatory drugs, which inhibit the enzyme to reduce pain, fever, and inflammation in tissues.

23. (D) IgE is primarily involved in allergic responses.
Immunoglobulins are specialized proteins that mediate various branches of the immune response. Immunoglobulin E is found in very low concentrations in the serum but plays a critical role in hypersensitivity and allergic reactions. It binds to mast cells and basophils, triggering the release of histamine and other inflammatory mediators when the body encounters specific allergens or certain parasitic infections.

24. (B) ΔH
Enthalpy is a thermodynamic property that represents the total heat content of a system at constant pressure. In biochemical reactions, the change in enthalpy reflects the difference between the energy required to break chemical bonds and the energy released when new bonds are formed. This parameter is a key component of the Gibbs free energy equation, influencing reaction spontaneity and direction.

25. (A) P-3, Q-4, R-1, S-2
Eukaryotic cells utilize specialized organelles to perform distinct biochemical tasks. Mitochondria generate the majority of cellular energy through ATP production, while lysosomes contain acid hydrolases for the degradation of macromolecules. The smooth endoplasmic reticulum is primarily responsible for lipid synthesis and detoxification, and the nucleolus serves as the specific site for ribosomal RNA synthesis and the assembly of ribosome subunits.

26. (C) It is driven by a decrease in the entropy of the system upon folding.
The hydrophobic effect is the primary driving force for protein folding and the formation of lipid bilayers. It is fundamentally an entropic phenomenon. When nonpolar molecules aggregate, the water molecules that were previously ordered around them are released into the bulk solvent. This release significantly increases the total entropy of the system, making the assembly of hydrophobic structures thermodynamically favorable.

27. (A) The equilibrium potential for a specific ion
The Nernst equation is used to calculate the theoretical equilibrium potential for a single ion species across a biological membrane. This potential represents the electrical force required to exactly balance the chemical driving force created by the concentration gradient of that

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ion. It is essential for understanding how cells establish resting membrane potentials and how they respond to changes in ion permeability.

28. (D) A neutral molecule with spatially separated positive and negative charges.
At physiological pH, most amino acids exist as zwitterions, which are molecular ions containing both positive and negative functional groups. Specifically, the amino group is protonated and carries a positive charge, while the carboxyl group is deprotonated and carries a negative charge. This dual ionization results in a molecule with no net charge, significantly influencing the physical and chemical behavior of proteins.

29. (B) Interconversion between alpha and beta anomeric forms
Mutarotation is the spontaneous change in the optical rotation of a sugar solution as it reaches equilibrium. This occurs because monosaccharides like glucose exist in a dynamic balance between their open-chain and cyclic hemiacetal forms. In water, the cyclic structures continuously interconvert between the alpha and beta anomeric configurations, eventually reaching a stable ratio that defines the final optical rotation.

30. (B) III only
Chloroplasts are the specialized organelles responsible for photosynthesis in plants and algae. They possess a complex triple-membrane system, including an outer envelope and internal thylakoids. The light-dependent reactions occur within the thylakoid membranes, where pigments capture solar energy. In contrast, the stroma is the site of the light-independent Calvin cycle, where carbon dioxide is fixed into organic sugars using ATP.

31. (D) Z-DNA
Under specific conditions such as high salt concentrations or negative supercoiling, DNA can transition from the standard B-form to Z-DNA. This structural variant is a left-handed helix with a characteristic zig-zag phosphate backbone. It is particularly favored by sequences consisting of alternating purine and pyrimidine bases, such as repeating GC steps, and may play a role in regulating gene expression.

32. (A) It separates particles based on sedimentation rate and size.
Differential centrifugation is a fundamental technique in cell biology used to isolate specific organelles from a cell homogenate. By applying sequential increases in centrifugal force, components are separated based on differences in their size and density. Larger, heavier structures like nuclei sediment quickly at low speeds, while smaller components such as mitochondria and microsomes require progressively higher speeds for isolation.

33. (B) To maintain distinct intracellular and extracellular signaling functions
Biological membranes exhibit structural asymmetry, meaning the lipid and protein compositions of the inner and outer leaflets are different. This arrangement is crucial for cellular functionality, as it allows for the specific localization of signaling molecules and receptors. For example, glycolipids are found exclusively on the outer surface for cell recognition, while certain signaling lipids are restricted to the inner leaflet.

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34. (D) Acetate is the primary buffering agent in human erythrocytes.
Physiological buffers are essential for maintaining the stable pH required for life. The bicarbonate system is the primary extracellular buffer in blood, while phosphate and proteins act as the main intracellular buffers. Hemoglobin also provides significant buffering capacity within red blood cells. In contrast, acetate is not a major physiological buffer in humans and is typically found only as a metabolic intermediate.

35. (C) A is true but R is false.
Saturated fatty acids have higher melting points than unsaturated ones because their straight chains allow for tight packing and maximize van der Waals interactions. In contrast, unsaturated fatty acids contain cis-double bonds that create permanent kinks in the hydrocarbon tail. These kinks prevent close packing, resulting in weaker intermolecular forces and significantly lower melting points for these oily, liquid molecules.

36. (D) Outer membrane containing lipopolysaccharides
Gram-negative bacteria possess a unique cell envelope architecture characterized by a thin peptidoglycan layer situated between an inner

plasma membrane and an asymmetric outer membrane. This outer membrane contains specialized molecules called lipopolysaccharides, which act as endotoxins and provide a selective permeability barrier. Gram-positive bacteria lack this outer membrane but feature a much thicker, multi-layered peptidoglycan cell wall with teichoic acids.

37. (A) It plots the phi (ϕ) and psi (ψ) dihedral angles of amino acid residues.
The Ramachandran plot is a vital tool in structural biology used to visualize the energetically allowed regions for backbone dihedral angles in a polypeptide. By plotting phi and psi angles, the diagram identifies conformations that avoid steric clashes between atoms. Different secondary structures, such as alpha-helices and beta-sheets, occupy distinct, predictable regions on the plot, assisting in protein structure validation.

38. (D) Succinate dehydrogenase
Marker enzymes are specific proteins localized within particular organelles, allowing researchers to identify and assess the purity of subcellular fractions. Succinate dehydrogenase is a component of both the citric acid cycle and the electron transport chain, making it an ideal marker for mitochondria. Other markers include acid phosphatase for lysosomes, catalase for peroxisomes, and glucose-six-phosphatase for the endoplasmic reticulum.

39. (C) Guanine pairs with Cytosine via two hydrogen bonds.
The Watson-Crick model describes DNA as a double helix with antiparallel strands held together by complementary base pairing. Adenine forms two hydrogen bonds with thymine, while guanine forms three hydrogen bonds with cytosine. This difference in bonding strength contributes to the overall stability of the helix and explains why sequences with higher GC content require more energy to denature or melt.

40. (A) Attachment, Penetration, Biosynthesis, Maturation, Lysis
The lytic cycle of a bacteriophage follows a strict sequence to produce new virions. It begins with the virus attaching to specific host receptors, followed by the injection of its genetic material. The host machinery is then hijacked to synthesize viral components during biosynthesis. These parts are assembled into new viruses during maturation, eventually leading to the rupture and destruction of the cell.

41. (B) Melting point
The physical properties of saturated fatty acids are directly influenced by their carbon chain length. As the number of carbons increases, the surface area for van der Waals interactions between adjacent molecules grows, leading to stronger intermolecular attraction. This results in a significant increase in the melting point, making longer-chain fatty acids more likely to be solid at physiological temperatures.

42. (A) Polar uncharged
Amino acids are classified based on the chemical properties of their side chains. Those containing a hydroxyl group, such as serine and threonine, are categorized as polar uncharged amino acids. The hydroxyl group allows these residues to participate in hydrogen bonding and serves as a common site for post-translational modifications like phosphorylation, which is critical for regulating protein function and signaling pathways.

43. (D) Facilitated diffusion
Facilitated diffusion is a passive transport mechanism that allows polar or charged molecules to cross the hydrophobic lipid bilayer through specific transmembrane proteins. Unlike active transport, it does not require cellular energy because molecules move down their concentration gradients. This process is saturable and highly specific, ensuring that only particular solutes are permitted to enter or exit the cell at controlled rates.

44. (B) Sugars differing only in the configuration around one specific carbon atom
Epimers are a specific class of diastereomers that differ in the spatial arrangement of atoms at only one chiral center. This structural relationship is common among monosaccharides with multiple asymmetric carbons. For example, D-glucose and D-mannose are epimers at the second carbon position. This minor difference is biochemically important as it dictates how these sugars interact with specific metabolic enzymes and transporters.

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45. (A) P-2, Q-3, R-1, S-4
Secondary metabolites are chemically diverse compounds used by plants for defense and signaling. Alkaloids are nitrogen-containing molecules often derived from amino acids, while phenolics feature hydroxyl groups attached to aromatic rings. Terpenoids are constructed from repeating isoprene units, and glycosides consist of a sugar molecule bound to a non-sugar moiety. Each class plays a unique role in the plant's ecological interactions.

46. (C) Vacuole - Storage and turgor maintenance
The plant vacuole is a large, membrane-bound organelle that performs several vital functions. It serves as a storage site for water, nutrients, and waste products while maintaining turgor pressure, which is essential for the structural integrity and growth of the plant cell. Other organelles have distinct roles, such as the rough endoplasmic reticulum for protein synthesis and mitochondria for energy production.

47. (A) First Law
The First Law of Thermodynamics, also known as the Law of Conservation of Energy, states that energy cannot be created or destroyed in an isolated system. It can only be transformed from one form to another, such as chemical energy being converted into mechanical work or heat. In biological systems, this law ensures that all energy changes are accounted for during metabolic processes.

48. (D) Plasma cells - Direct targeted cell lysis
The immune system comprises various cells with specialized functions for defense. T-cells and B-cells mediate adaptive immunity, with B-cells differentiating into plasma cells that secrete antibodies. Macrophages perform phagocytosis to eliminate pathogens. In contrast, plasma cells do not directly lyse target cells; instead, their secreted antibodies mark pathogens for destruction by other components of the immune system, such as complement proteins.

49. (B) By increasing the permeability of the membrane to specific ions
Ionophores are small, hydrophobic molecules that facilitate the movement of ions across biological membranes. They function by either forming a hydrophilic channel or by acting as mobile carriers that shield the ion's charge from the hydrophobic core of the lipid bilayer. By increasing membrane permeability to specific ions, they dissipate electrochemical gradients, which can disrupt essential cellular processes like ATP synthesis.

50. (B) I and III
Quaternary structure refers to the assembly of multiple individual polypeptide subunits into a single functional protein complex. This level of organization is primarily stabilized by non-covalent interactions, such as hydrophobic forces and hydrogen bonds, rather than covalent peptide bonds. Hemoglobin is the classic example of a quaternary protein, consisting of four distinct globin subunits that work cooperatively to transport oxygen.

51. (B) The ratio of saturated to unsaturated fatty acid tails
Membrane fluidity is a critical physical property determined largely by the chemical composition of the lipid bilayer. Unsaturated fatty acids contain double bonds that create kinks, preventing tight packing and increasing fluidity. Conversely, saturated fatty acids have straight chains that pack closely together, making the membrane more rigid. Cells can adjust this ratio to maintain optimal membrane function in response to environmental changes.

52. (A) Cooperative binding among quaternary subunits
Hemoglobin exhibits a sigmoidal oxygen-binding curve due to cooperativity between its four subunits. When one oxygen molecule binds, it induces a conformational change that increases the affinity of the remaining subunits for oxygen. Myoglobin, a monomeric protein, lacks this quaternary interaction and displays a hyperbolic curve. This cooperative behavior allows hemoglobin to efficiently load oxygen in the lungs and release it in tissues.

53. (C) Isoelectric point (pI)
The isoelectric point is the specific pH at which a molecule, such as an amino acid or protein, carries no net electrical charge. At this pH, the number of positive charges exactly equals the number of negative charges. This property is significant because molecules at their pI are generally least soluble in water and will not migrate when placed in an electric field.

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54. (B) Starch
Polysaccharides are classified into structural and storage types based on their biological roles. Cellulose and chitin are structural polymers that provide rigidity to cell walls and exoskeletons, respectively. In contrast, starch is a storage polysaccharide used by plants to reserve glucose for future energy needs. It is easily broken down by enzymes when the organism requires metabolic fuel for cellular processes.

55. (A) Both A and R are true and R is the correct explanation of A.
The inner mitochondrial membrane is uniquely designed with high protein content and a lack of porins, making it highly impermeable to most ions. This structural property is essential for the establishment of a stable proton gradient across the membrane. This gradient provides the electrochemical driving force used by ATP synthase to produce adenosine triphosphate during the process of oxidative phosphorylation.

56. (A) The presence of one or more phosphate groups
Nucleosides and nucleotides are the building blocks of nucleic acids, consisting of a nitrogenous base and a pentose sugar. A nucleoside becomes a nucleotide upon the addition of at least one phosphate group through a phosphoester bond. These phosphate groups are critical for the molecule's role in genetic information storage and energy transfer, as seen in adenosine triphosphate and DNA strands.

57. (C) rRNA
During the process of translation, the ribosome serves as the machinery for synthesizing proteins. While many proteins contribute to the structure of the ribosome, it is the ribosomal RNA itself that acts as a ribozyme. Specifically, the large subunit rRNA catalyzes the formation of peptide bonds between amino acids, demonstrating that RNA can have fundamental catalytic functions in the cell.

58. (C) They are derived from 20-carbon polyunsaturated fatty acids like arachidonic acid.
Eicosanoids are a family of potent signaling molecules, including prostaglandins and leukotrienes, that are synthesized from twenty-carbon polyunsaturated fatty acids. They are typically produced on demand from membrane lipids like arachidonic acid and function as local hormones. They regulate diverse physiological processes such as inflammation, blood clotting, and smooth muscle contraction, acting primarily on nearby cells via specific receptors.

59. (D) Carbohydrates
Carbohydrates are a fundamental class of biomolecules composed of carbon, hydrogen, and oxygen, generally following the stoichiometric ratio of one water molecule per carbon atom. This general formula reflects their chemical nature as polyhydroxy aldehydes or ketones. They serve diverse roles in living organisms, ranging from being the primary source of metabolic energy to providing essential structural support in cell walls.

60. (A) I, II and IV
The hydrophobic effect is the major thermodynamic force driving the assembly of biological structures like protein folds and lipid bilayers. It is primarily an entropic process. When nonpolar surfaces aggregate, the surrounding water molecules are released from an ordered state into a disordered one, increasing the system's total entropy. This spontaneous process minimizes the exposure of hydrophobic regions to the aqueous environment.

61. (A) One fatty acid chain is replaced by a phosphate and a polar head group.
Glycerophospholipids are the primary structural components of biological membranes. They share a glycerol backbone with triacylglycerols, which are used for energy storage. However, in a phospholipid, only two fatty acids are attached to the glycerol, while the third position is occupied by a phosphate group linked to a polar head group. This amphipathic structure allows them to form stable bilayers.

62. (A) Primary structural component of the cell membrane
Plant phenolics are a large class of secondary metabolites that perform various ecological and protective roles. They are involved in defense against herbivores, attraction of pollinators through color, and protection against oxidative stress from ultraviolet radiation. Unlike phospholipids or proteins, phenolics do not serve as primary structural components of the cell membrane, although they may influence its overall stability and properties.

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63. (B) They secrete large amounts of circulating antibodies.
T-cells are essential components of the adaptive immune system that mature in the thymus and mediate cell-mediated immunity. Helper T-cells coordinate the response by secreting cytokines, while cytotoxic T-cells directly kill infected cells. In contrast, the secretion of large amounts of circulating antibodies is the specialized function of plasma cells, which are the activated form of the B-cell lineage.

64. (B) Hydrophobic collapse hiding nonpolar residues from water
The spontaneous folding of globular proteins is primarily driven by the hydrophobic effect. In an aqueous environment, nonpolar amino acid side chains tend to aggregate in the protein's interior to minimize their contact with water. This hydrophobic collapse is thermodynamically favorable because it increases the entropy of the surrounding water molecules, resulting in a stable, compact three-dimensional functional conformation for the protein.

65. (A) P-2, Q-4, R-1, S-3
The immune system utilizes diverse components to protect the body from pathogens. Antigens are molecules that trigger an immune response, while immunoglobulins are specific proteins that bind to them. Macrophages are phagocytic cells that engulf foreign particles, and B-cells are the specialized lymphocytes that mature in the bone marrow and differentiate into antibody-producing cells upon activation by specific foreign antigens.

66. (B) Coupling to a highly exergonic reaction like ATP hydrolysis
Endergonic reactions require an input of energy to proceed because they result in an increase in free energy. In biological systems, these unfavorable reactions are made possible by coupling them to highly exergonic processes, such as the hydrolysis of adenosine triphosphate. The combined net free energy change of the coupled reactions becomes negative, allowing the overall process to occur spontaneously under physiological conditions.

67. (A) NADH
NADH is the reduced form of the essential coenzyme nicotinamide adenine dinucleotide. It acts as a major electron carrier in the cell, accepting electrons during the breakdown of nutrients and donating them to the electron transport chain during oxidative phosphorylation. This transfer of electrons is critical for the generation of the proton gradient that eventually drives the synthesis of cellular energy.

68. (D) A fatty acid that must be obtained through dietary intake.
Essential fatty acids are specific polyunsaturated fats that the human body cannot synthesize because it lacks the enzymes required to introduce double bonds at certain positions. Therefore, these molecules must be obtained from dietary sources. They are vital for the synthesis of important signaling molecules like eicosanoids and for maintaining the structural integrity and optimal fluidity of cellular membranes.

69. (B) By its specific infectivity toward bacterial cells
Bacteriophages are a specialized category of viruses that exclusively infect and replicate within bacterial hosts. They are generally classified by their unique host specificity and structural features, such as a protein capsid and often a complex head-tail morphology. Unlike bacteria, they are non-living entities that hijack the host's cellular machinery to produce new viral particles through either lytic or lysogenic cycles.

70. (B) V only
Membrane transport involves various mechanisms to move solutes across the lipid bilayer. Passive diffusion occurs without proteins, while facilitated diffusion uses specific, saturable carriers. Primary and secondary active transport mechanisms move solutes against gradients using energy. Ionophores are molecules that actually increase membrane permeability to specific ions by acting as mobile carriers or channel formers, thereby dissipating established electrochemical gradients.

71. (C) Exactly 0
When a chemical reaction reaches equilibrium, the rates of the forward and reverse reactions are equal, and there is no net change in the concentrations of reactants and products. At this state, the Gibbs free energy change is zero, indicating that the system is at its lowest energy state and can no longer perform useful work under constant conditions.

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72. (D) Carrying specific amino acids to the ribosome
Transfer RNA acts as a crucial adapter molecule during the process of translation. Each tRNA molecule contains an anticodon that recognizes a specific codon on the messenger RNA template. It also carries the corresponding amino acid attached to its acceptor stem. By bringing the correct amino acids to the ribosome in sequence, tRNA ensures that the genetic code is accurately translated.

73. (D) They are synonymous with protein quaternary structure.
Protein domains are independent structural and functional units within a single polypeptide chain that can fold and function autonomously. A single protein may contain multiple domains, each contributing a different activity. In contrast, quaternary structure refers to the arrangement of multiple separate polypeptide chains into a larger complex. Domains are part of the tertiary structure and are not equivalent to quaternary organization.

74. (C) Solution pH based on buffer concentration ratios
The Henderson-Hasselbalch equation is a fundamental mathematical relationship used to calculate the pH of a buffer solution. It relates the pH to the acid dissociation constant of a weak acid and the ratio of the concentrations of the conjugate base and the acid. This equation is essential for understanding how physiological systems maintain stable pH environments despite various metabolic changes.

75. (A) Both A and R are true and R is the correct explanation of A.
Chitin is a robust structural polysaccharide that provides rigidity to fungal cell walls and the exoskeletons of arthropods. It is composed of linear chains of N-acetylglucosamine units joined by beta one-four glycosidic bonds. These linkages allow for extensive hydrogen bonding between adjacent chains, creating a tough and insoluble fiber that protects the organism and maintains its physical shape and integrity.

76. (A) 3.6
The alpha-helix is a common secondary structure in proteins characterized by a right-handed coiled conformation. In a standard alpha-helix, there are approximately three point six amino acid residues per complete turn. This specific geometry allows for the formation of stable intramolecular hydrogen bonds between the carbonyl oxygen of one residue and the amide hydrogen of the residue four positions away.

77. (A) The change in optical rotation of a sugar solution until equilibrium is reached
Mutarotation is the physical phenomenon where the optical rotation of a freshly prepared sugar solution changes over time until it reaches a constant value. This occurs because cyclic monosaccharides like glucose spontaneously interconvert between their alpha and beta anomeric forms in water. Eventually, the solution achieves a dynamic equilibrium between these two configurations, resulting in a stable and characteristic optical rotation.

78. (D) rRNA - Catalytic core of ribosomes
Ribosomes are the cellular machines responsible for protein synthesis, composed of both proteins and ribosomal RNA. The rRNA serves not just as a structural scaffold but also as the actual catalyst for peptide bond formation, acting as a ribozyme. This catalytic function is central to translation, emphasizing that nucleic acids can perform enzymatic roles historically attributed only to protein molecules.

79. (D) Lysosome - Alkaline pH interior
Lysosomes are specialized eukaryotic organelles responsible for the intracellular degradation of macromolecules. They contain a variety of hydrolytic enzymes that are most active under acidic conditions. To facilitate this, lysosomes maintain an internal pH of approximately five, which is much lower than the neutral cytosol. This acidity is achieved by the action of proton pumps located in the lysosomal membrane.

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80. (B) Identify pK_1 and pK_2, add them, divide by 2
The isoelectric point of a neutral amino acid is the specific pH at which it has no net electrical charge. For amino acids with non-ionizable side chains, like glycine, this value is calculated by taking the arithmetic mean of the two pKa values corresponding to the alpha-carboxyl and alpha-amino groups. At this pH, the molecule exists primarily in its zwitterionic form.

81. (A) The high-energy phosphoanhydride bond in ATP
Adenosine triphosphate is the universal energy currency of the cell due to its two high-energy

phosphoanhydride bonds. The hydrolysis of these bonds is highly exergonic because it relieves electrostatic repulsion and increases resonance stability. By coupling this energy release to endergonic metabolic reactions, the cell can drive unfavorable processes forward, ensuring that vital biological functions proceed at appropriate rates and times.

82. (D) Glycerophospholipid
Amphipathic molecules possess both distinct hydrophilic and hydrophobic regions within the same structure. Glycerophospholipids are a classic example, featuring a polar head group and two nonpolar fatty acid tails. This dual nature is essential for the spontaneous formation of biological membranes, as the hydrophobic tails aggregate away from water while the polar heads interact with the aqueous environment on both sides.

83. (C) Cytosine
Nucleic acids contain nitrogenous bases classified into purines and pyrimidines. Cytosine and thymine are the primary pyrimidines found in DNA, while uracil replaces thymine in RNA. Adenine and guanine are purines. Among the options, cytosine is a pyrimidine that occurs in DNA. Its specific hydrogen-bonding pattern with guanine is critical for the stability and accurate replication of the genetic material during division.

84. (A) The activation energy barrier is too high for physiological rates.
Enzymes are biological catalysts that significantly increase the speed of chemical reactions by lowering the activation energy barrier. Without catalysis, most biochemical processes would proceed far too slowly to sustain life at physiological temperatures. Importantly, enzymes do not change the overall free energy of the reaction or its equilibrium constant; they only accelerate the rate at which equilibrium is reached.

85. (A) P-2, Q-4, R-1, S-3
Lipids are categorized by their diverse chemical structures and biological roles. Glycerophospholipids like phosphatidylserine are major membrane components, while sphingolipids such as ceramide serve both structural and signaling functions. Sterols like cholesterol modulate membrane properties and act as hormone precursors. Eicosanoids, including prostaglandin E2, are potent local signaling molecules derived from polyunsaturated fatty acids that regulate inflammation and other processes.

86. (B) Increased presence of cholesterol
Cholesterol acts as a critical buffer for membrane fluidity in animal cells. At physiological temperatures, its rigid steroid nucleus interferes with the movement of phospholipid fatty acid chains, thereby decreasing membrane fluidity and increasing stability. However, at lower temperatures, it prevents the membrane from solidifying by disrupting the regular packing of lipids, ensuring that the membrane remains functional across environmental ranges.

87. (A) Unequal distribution of ions and electrical charges across the lipid bilayer
An electrochemical gradient is created by the combined effect of a concentration difference of ions and an electrical potential across a biological membrane. This occurs when ions are unevenly distributed between the intracellular and extracellular spaces, often due to the action of active transport pumps. This gradient serves as a source of stored energy for processes like nutrient uptake and signaling.

88. (D) FAD is typically covalently or tightly bound to its respective enzyme.
FAD and NAD^+ are essential electron carriers, but they interact differently with enzymes. NAD^+ typically functions as a mobile coenzyme that dissociates from the enzyme after the reaction. In contrast, FAD is usually a prosthetic group that remains tightly or covalently bound to its apoenzyme. This allow FAD to participate in sequential electron transfers within a single protein complex during metabolism.

89. (B) Branched storage polysaccharide
Glycogen is the primary glucose storage molecule in animals and is characterized by a highly branched structure. It consists of glucose units linked by alpha one-four bonds, with frequent alpha one-six branches. This extensive branching increases the solubility of the molecule and provides numerous ends for enzymes to rapidly release glucose, which is essential for maintaining blood sugar levels.

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90. (A) I and II
Secondary metabolites are specialized compounds that assist in plant survival and defense. Alkaloids are nitrogen-containing molecules often possessing basic properties, while terpenoids are constructed from five-carbon isoprene units. Phenolics, contrary to some descriptions, are defined by the presence of at least one aromatic ring with one or more hydroxyl groups attached, which contributes to their roles as antioxidants and defense agents.

91. (D) A compact reversal of chain direction involving four residues.
A beta-turn is a common secondary structure motif that allows a polypeptide chain to abruptly change direction, often connecting antiparallel beta-strands. This compact structure typically consists of four amino acid residues, with a characteristic hydrogen bond between the carbonyl oxygen of the first residue and the amide hydrogen of the fourth. These turns are essential for the folding of globular proteins.

92. (C) -1
Aspartic acid is an acidic amino acid with an ionizable side chain. At physiological pH of approximately seven point four, both the alpha-carboxyl group and the side-chain carboxyl group are deprotonated and carry negative charges, while the alpha-amino group remains protonated and carries a positive charge. Consequently, the net charge of the molecule is negative one, which influences its interactions in proteins.

93. (B) It invariably breaks the primary peptide bonds.
Protein denaturation is the process by which a protein loses its native three-dimensional conformation due to external stress like heat or chemical agents. This process disrupts non-covalent interactions and disulfide bridges but does not involve the cleavage of the primary peptide bonds. Although the primary sequence remains intact, the loss of secondary and tertiary structure typically leads to a complete loss of function.

94. (C) Antiporters
Membrane transporters are classified by the direction and number of solutes they move. Antiporters are specialized proteins that facilitate the simultaneous transport of two different molecules or ions across the membrane in opposite directions. This mechanism is often used to maintain specific ion balances or to drive the uphill transport of one molecule using the downhill gradient of another in secondary active transport.

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95. (A) Both A and R are true and R is the correct explanation of A.
Oleic acid and stearic acid both have eighteen carbon atoms, but oleic acid is unsaturated with one cis-double bond. This double bond introduces a permanent bend or kink in the hydrocarbon chain, which prevents the molecules from packing as tightly as the straight-chain saturated stearic acid. As a result, oleic acid has fewer van der Waals interactions and a significantly lower melting point.

96. (A) A linkage between a carboxylic acid and a thiol group
A thioester bond is a high-energy chemical linkage formed by the condensation of a carboxylic acid with a thiol group. In biochemistry, these bonds are particularly important in molecules like acetyl-CoA. They are more reactive than standard oxygen esters because they lack significant resonance stabilization. This high energy of hydrolysis makes thioesters excellent intermediates for driving various metabolic reactions and group transfers.

97. (A) The single hydroxyl group at position C-3
Cholesterol is an amphipathic molecule essential for membrane integrity. Its structure consists of a large, hydrophobic four-ring steroid nucleus and a short hydrocarbon tail, which anchor it within the lipid bilayer. The molecule's amphipathic nature arises from the presence of a single polar hydroxyl group at the third carbon position. This group interacts with the aqueous environment or polar head groups of phospholipids.

98. (B) Adenine and Guanine
Nucleic acids are composed of nitrogenous bases classified into purines and pyrimidines. Adenine and guanine are the two purines that are found in both DNA and RNA molecules. These double-ring structures play central roles in genetic coding and energy transfer. In contrast, the pyrimidine bases differ between the two types of nucleic acids, with thymine found in DNA and uracil found in RNA.

99. (B) ΔH - Enthalpy change
Thermodynamic parameters are used to describe the energy changes in biochemical systems. ΔG represents the change in Gibbs free energy, which determines reaction spontaneity. ΔH signifies the change in enthalpy, or the heat content of the system, and T is the absolute temperature in Kelvin. ΔS denotes the change in entropy, which is a measure of the system's disorder.

100. (B) II, III and IV
Biological membranes are asymmetric, meaning the distribution of lipids differs between the two leaflets. Phosphatidylserine is typically localized to the inner leaflet, while glycolipids are found on the extracellular surface. This asymmetry is vital for cellular signaling and recognition. Specialized enzymes called flippases and floppases actively maintain this unequal distribution, while scramblases can randomize the lipids during specific cellular events.

101. (A) Differential centrifugation
Differential centrifugation is a common laboratory technique used to separate subcellular components based on their different sedimentation rates. By subjecting a cell homogenate to progressively higher centrifugal forces, larger and denser particles like nuclei pellet first, followed by mitochondria, and then smaller microsomes. This stepwise process allows researchers to isolate specific organelles for further biochemical analysis and study of their unique functions.

102. (D) tRNA
Transfer RNA molecules are small nucleic acids characterized by a unique cloverleaf secondary structure and an L-shaped three-dimensional form. They contain numerous modified bases, such as pseudouridine and dihydrouridine, which are essential for their stability and function. Each tRNA serves as an adapter that carries a specific amino acid to the ribosome, ensuring the accurate translation of the genetic code into proteins.

103. (C) A molecule capable of inducing an immune response
An antigen is defined as any substance, typically a protein or polysaccharide, that the immune system recognizes as foreign. Upon recognition, these molecules elicit a specific immune response, which includes the production of antibodies or the activation of T-cells. Antigens possess specific regions called epitopes that bind to receptors on immune cells, allowing for highly targeted defense against pathogens and foreign substances.

104. (D) The presence of organelle-specific membrane barriers and local environments
Eukaryotic cells utilize membrane-bound organelles to compartmentalize specific metabolic pathways, preventing incompatible reactions from occurring simultaneously. Each organelle provides a unique local environment with specialized enzymes, substrates, and pH levels tailored to its specific function. This spatial organization enhances metabolic efficiency and allows for sophisticated regulation of cellular processes, which is a hallmark of eukaryotic complexity compared to simpler prokaryotic cells.

105. (A) P-3, Q-2, R-4, S-1
Biochemical principles provide the framework for understanding cellular processes. The Henderson-Hasselbalch equation calculates buffer pH, while the Nernst equation determines reduction potentials and ion equilibrium. Gibbs free energy change predicts whether a reaction is spontaneous. The Ramachandran plot is used to predict the energetically favorable backbone conformations of amino acids in proteins, ensuring that structural models are sterically feasible and accurate.

106. (D) Arachidonic acid
Prostaglandins are potent lipid mediators synthesized from arachidonic acid, a twenty-carbon polyunsaturated fatty acid. This precursor is released from membrane phospholipids by the action of phospholipase enzymes in response to various stimuli. Once free, arachidonic acid enters the cyclooxygenase pathway, where it is converted into prostaglandins that regulate essential physiological functions, including inflammatory responses, blood flow, and the protection of the gastric mucosa.

107. (A) By containing significant amounts of a weak acid and its conjugate base to absorb added H^+ or OH^-
A buffer system resists changes in pH by utilizing a mixture of a weak acid and its conjugate base. When strong acids are added, the conjugate base reacts with the excess protons. Conversely, the

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weak acid neutralizes added strong bases. This dual capacity allows the solution to maintain a relatively stable hydrogen ion concentration, which is vital for preserving the structure and function of biological molecules.

108. (D) They are enclosed in a protein coat known as a capsid.
Viruses are non-cellular infectious agents that consist of a genetic core, either DNA or RNA, surrounded by a protective protein shell called a capsid. Unlike living cells, they lack metabolic machinery, ribosomes, and the ability to generate energy independently. They are obligate intracellular parasites that must hijack the host cell's resources and biological processes to replicate and produce new viral particles.

109. (A) Nuclei, Mitochondria, Microsomes, Cytosol
During the process of differential centrifugation, subcellular components are separated according to their sedimentation rates, which are determined by size and density. The largest and densest particles, the nuclei, form a pellet at the lowest speeds. Mitochondria sediment next at moderate speeds, followed by microsomes at high speeds. The remaining soluble portion of the homogenate, containing dissolved molecules and small complexes, constitutes the final supernatant.

110. (A) I and II
Redox reactions involve the transfer of electrons between molecules. Oxidation is defined as the loss of electrons, while reduction is the gain of electrons. In biological systems, these transfers are often mediated by carriers like NAD+ and FAD. Standard reduction potentials help determine the direction of electron flow. Misunderstanding these basic definitions can lead to incorrect conclusions about the energetics and directionality of metabolic pathways.

111. (D) $\Delta G'^{\circ}$
In biochemistry, the standard free energy change is defined at a specific standard state that includes a pH of seven point zero. This is because most biological reactions occur in aqueous environments near neutral pH, rather than at the unit concentration of hydrogen ions required for the standard chemical state. This parameter provides a more physiologically relevant measure of the energy available from metabolic reactions.

112. (A) They arise from the tendency of water molecules to maximize their own entropy.
Hydrophobic interactions are not traditional chemical bonds but are driven by the behavior of water molecules. When nonpolar molecules are placed in water, the solvent forms ordered cages around them, which is entropically unfavorable. The aggregation of hydrophobic surfaces minimizes this contact, releasing water molecules into the bulk solvent and significantly increasing the total entropy of the system, thereby stabilizing biological structures.

113. (B) The measure of a molecule's tendency to donate or accept electrons
Standard reduction potential is a thermodynamic parameter that quantifies the affinity of a chemical species for electrons under standardized conditions. A more positive potential indicates a greater tendency to be reduced by accepting electrons. In the mitochondrial electron transport chain, electrons flow spontaneously from molecules with lower potentials to those with higher potentials, allowing the cell to capture released energy for ATP synthesis.

114. (B) It is the primary site of intracellular lipid synthesis.
The rough endoplasmic reticulum is a specialized organelle characterized by the presence of ribosomes on its surface. It plays a central role in the synthesis and initial folding of proteins destined for secretion or membrane insertion. While it participates in protein glycosylation, it is not the primary site for lipid synthesis; that function is localized to the smooth endoplasmic reticulum, which lacks attached ribosomes.

115. (A) Separates organelles based on their specific buoyant densities.
Density gradient centrifugation is a refined separation technique that utilizes a medium with a continuous or step-wise increase in density. Particles move through the gradient until they reach a position where their own density matches that of the surrounding medium. This method allows for the precise isolation of organelles that might have similar sizes but different buoyant densities, providing higher purity than differential centrifugation.

116. (C) Zwitterion
A zwitterion is a molecular ion that contains an equal number of positively and negatively

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charged functional groups, resulting in a net electrical charge of zero. Amino acids typically adopt this form at physiological pH, with a protonated amino group and a deprotonated carboxyl group. This state is central to the physical properties of amino acids, such as their high melting points and solubility.

117. (A) Secondary is local folding, while tertiary is the 3D shape.
Secondary structure refers to the localized, regular folding patterns of the polypeptide backbone, such as alpha-helices and beta-sheets, which are stabilized by hydrogen bonds. In contrast, tertiary structure describes the overall three-dimensional conformation of the entire polypeptide chain. It is formed by the long-range interactions between amino acid side chains, including hydrophobic forces, ionic bonds, and covalent disulfide bridges, resulting in functional proteins.

118. (D) Alpha-linolenic acid - Omega-3
Fatty acids are classified based on the position of the first double bond from the methyl end of the chain. Alpha-linolenic acid is an essential omega-three fatty acid, meaning the first double bond is at the third carbon atom. This classification is important because humans cannot synthesize these fats and must obtain them from the diet to support brain health and reduce systemic inflammation.

119. (D) Phosphodiester bond - Linkage between bases
Nucleic acids are polymers composed of nucleotides linked by phosphodiester bonds. These bonds connect the three-prime hydroxyl group of one pentose sugar to the five-prime phosphate group of the next, forming the structural backbone of the molecule. The nitrogenous bases, such as adenine and uracil, are attached to the sugars but are not directly linked to each other by phosphodiester bonds; they participate in base pairing.

120. (A) II, IV, I, III
Protein structure is organized into a hierarchy of four levels. Primary structure is the linear sequence of amino acids. Secondary structure involves local folding like alpha-helices. Tertiary structure is the final three-dimensional shape of a single chain. Quaternary structure occurs when multiple folded chains assemble into a functional complex. This specific order reflects the progression of folding from a simple strand to a complex molecule.

121. (C) Phenolics
Plant phenolics are a diverse group of secondary metabolites, including tannins and flavonoids, that are primarily synthesized through the shikimate pathway. This pathway converts simple carbohydrate precursors into aromatic amino acids like phenylalanine, which then serve as the foundation for various phenolic structures. These compounds are essential for plant defense against herbivores and provide protection from environmental stresses like excessive ultraviolet radiation.

122. (A) Mediating inflammation and smooth muscle contraction
Prostaglandins are bioactive lipid signaling molecules that function primarily as local hormones. They are involved in a wide range of physiological processes, most notably the mediation of inflammation, pain, and fever. Additionally, they regulate smooth muscle contraction in various organs and influence blood flow. Their production is tightly controlled, and they act through specific receptors to coordinate localized cellular responses to injury or physiological stimuli.

123. (D) Upon activation, they differentiate into antibody-secreting plasma cells.
B-cells are a key component of the adaptive immune system that mature in the bone marrow. When they encounter a specific antigen, they undergo activation and clonal expansion. Most of these cells then differentiate into plasma cells, which are specialized factories that produce and secrete large quantities of antibodies. These antibodies circulate in the blood and help neutralize or mark pathogens for destruction by other cells.

124. (D) Glycosidic bond
A glycosidic bond is a type of covalent linkage that joins a carbohydrate molecule to another group, which may be another sugar. This bond specifically involves the anomeric carbon of the sugar and a hydroxyl group from the second molecule. These linkages are the fundamental bonds that hold monosaccharides together to form complex disaccharides, oligosaccharides,

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and polysaccharides like starch and cellulose in living organisms.

125. (C) Enthalpy (H)
In thermodynamics, a state function is a property of a system that depends only on its current state, not on the path taken to reach that state. Enthalpy is a state function that represents the total heat content of a biochemical system. Other common state functions include temperature, pressure, and Gibbs free energy. In contrast, work and heat are path functions because their values depend on the process.

126. (B) A sphingosine backbone attached to a fatty acid via an amide bond
Sphingolipids are a major class of membrane lipids that differ from glycerolipids by having a sphingosine backbone instead of glycerol. A single fatty acid is attached to the amino group of sphingosine through an amide bond, forming a molecule called ceramide. This core structure can be further modified with various polar head groups to create more complex sphingolipids, which are essential for structural integrity and signaling.

127. (D) Stabilizes the bilayer by driving nonpolar tails from water.
The hydrophobic effect is the primary force responsible for the spontaneous assembly and stability of biological membranes. In an aqueous environment, amphipathic lipid molecules arrange themselves into a bilayer where the nonpolar hydrocarbon tails are shielded in the interior. This aggregation minimizes the contact between the hydrophobic tails and water, increasing the entropy of the surrounding solvent and creating a stable, semi-permeable barrier.

128. (B) Uses ATP to move solutes against concentration gradients.
Primary active transport is a mechanism where molecules or ions are moved across a membrane against their concentration gradient using energy derived directly from the hydrolysis of adenosine triphosphate. This distinguishes it from facilitated diffusion, which is a passive process that only moves solutes down their gradients without energy input. Primary transport systems are essential for establishing the electrochemical gradients used by many other cellular processes.

129. (B) Change in rotation due to anomer interconversion in solution.
Mutarotation is the process where the optical rotation of a sugar solution changes over time as it reaches a stable equilibrium. This occurs because the cyclic forms of monosaccharides, the alpha and beta anomers, spontaneously interconvert through an open-chain intermediate. Eventually, a dynamic balance is established between the two forms, resulting in a characteristic final rotation value for the specific sugar being studied.

130. (B) Amylose is a linear polymer, while amylopectin is branched.
Starch is the primary storage carbohydrate in plants and consists of two types of glucose polymers. Amylose is a largely linear chain of glucose units linked by alpha one-four glycosidic bonds. In contrast, amylopectin is a highly branched molecule, featuring alpha one-six glycosidic linkages at the branching points in addition to the linear alpha one-four bonds. This branching allows for more efficient glucose storage and mobilization.

131. (B) Proline
Proline is often called an imino acid because its side chain is cyclized and covalently bonded back to the nitrogen of the amino group. This rigid ring structure significantly restricts the conformational flexibility of the polypeptide backbone wherever proline is present. Consequently, it often acts as a helix breaker in secondary structures and is frequently found at the turns and bends of protein three-dimensional folds.

132. (A) Antiparallel sheets are more stable due to linear H-bonds.
Beta-sheets are protein secondary structures where polypeptide strands are held together by hydrogen bonds between the backbone groups. In antiparallel sheets, the strands run in opposite directions, allowing for the formation of linear, straight hydrogen bonds that are optimally aligned. In parallel sheets, the strands run in the same direction, resulting in distorted, angled hydrogen bonds that are inherently weaker and less stable than those in antiparallel sheets.

133. (D) The increase in the kinetic energy overcoming non-covalent stabilizing forces
Protein denaturation upon heating is a thermodynamic process where increased

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kinetic energy disrupts the weak, non-covalent interactions that stabilize the native structure. Hydrogen bonds, hydrophobic interactions, and ionic forces are overcome by the thermal agitation, causing the protein to unfold into a disordered state. This unfolding increases the conformational entropy of the polypeptide chain, making the process favorable at high temperatures despite the loss of stabilizing bonds.

134. (C) The omega-carbon is the carboxyl carbon.
Fatty acid nomenclature uses specific conventions to identify carbon atoms. In the delta system, numbering begins with the carboxyl carbon as carbon one. In contrast, the omega system identifies the position of double bonds relative to the methyl end of the chain, with the methyl carbon designated as the omega carbon. Understanding these systems is essential for classifying fatty acids and their roles in nutrition and metabolism.

135. (A) Sphingoglycolipids (Sphingolipids with carbohydrate heads)
The human ABO blood group antigens are complex carbohydrate structures found on the surface of red blood cells. These antigens are attached to specialized membrane lipids called sphingoglycolipids, where a sugar chain is linked to a ceramide backbone. The specific sequence and arrangement of these sugars are genetically determined, and they serve as critical recognition markers for the immune system, dictating compatibility during blood transfusions.

136. (D) Covalent bonding between complementary bases
The DNA double helix is stabilized by several non-covalent interactions, including hydrogen bonds between base pairs, the hydrophobic effect in the core, and van der Waals stacking forces. These weak interactions allow the strands to be separated during replication and transcription. Covalent bonds are present only in the sugar-phosphate backbone and between the sugar and the base; they do not exist between the complementary bases of opposing strands.

137. (B) Splicing of pre-mRNA transcripts
Small nuclear RNAs are a specialized class of RNA molecules found within the eukaryotic nucleus. They associate with specific proteins to form small nuclear ribonucleoproteins, which are the primary components of the spliceosome. This complex is responsible for the precise removal of introns from pre-messenger RNA and the joining of exons. This splicing process is essential for generating functional mRNA templates that can be accurately translated.

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138. (A) The presence of a basic nitrogen atom, typically within a heterocyclic ring
Alkaloids are a major class of plant secondary metabolites characterized by the presence of at least one nitrogen atom, which is usually part of a complex ring structure. These compounds often exhibit basic properties and are derived from various amino acid precursors. Alkaloids are well-known for their potent physiological effects on animals and humans, and they serve primarily as defensive agents for plants against various herbivores.

139. (C) The pathway relies entirely on the degradation of structural cellular proteins.
The arachidonic acid cascade is a critical signaling pathway involved in inflammation and physiological regulation. It begins with the release of arachidonic acid from membrane phospholipids, not from proteins, by the action of phospholipase enzymes. This fatty acid is then metabolized by either cyclooxygenase or lipoxygenase to produce bioactive molecules like prostaglandins and leukotrienes, which mediate diverse cellular responses to injury and external stimuli.

140. (A) II, IV, I, III
An adaptive immune response begins with the capture and presentation of antigens by specialized cells like macrophages. These antigens are then recognized by specific T-cells, which trigger their activation and clonal expansion to create a large population of effector cells. These cells, along with secreted antibodies, work to eliminate the pathogen from the body, eventually leaving behind memory cells that provide long-term protection against future infections.

141. (B) The sedimentation coefficient, primarily dependent on size and density
Differential centrifugation separates subcellular components based on their different sedimentation rates when subjected to centrifugal force. This rate is quantified by the sedimentation coefficient, which depends on the particle's size, shape, and density relative to the medium. By

measuring how quickly different organelles form a pellet, researchers can effectively fractionate a cell homogenate to isolate specific structures like nuclei, mitochondria, and ribosomes for detailed analysis.

142. (A) $\Delta G = \Delta H - T\Delta S$
The Gibbs free energy equation is a fundamental relationship in thermodynamics that determines the spontaneity of biological processes. It states that the change in free energy is equal to the change in enthalpy minus the product of the absolute temperature and the change in entropy. A negative value for free energy indicates that a process is spontaneous and can occur without external energy input under constant conditions.

143. (B) Lysosome - Acid phosphatase
Marker enzymes are specific proteins that are uniquely localized to particular cellular organelles, allowing researchers to verify the success of fractionation procedures. Acid phosphatase is the standard marker for lysosomes because it functions optimally in their acidic environment. Other examples include succinate dehydrogenase for mitochondria and catalase for peroxisomes. The presence of these enzymes in a fraction indicates the presence of the corresponding organelle.

144. (A) Determining the resting membrane potential created by ion gradients
The Nernst equation provides a mathematical way to calculate the equilibrium potential for a specific ion based on its concentration gradient across a cell membrane. In biological systems, this equation is essential for understanding how the unequal distribution of ions contributes to the overall resting membrane potential. This electrical potential is a form of stored energy used for transmitting signals and driving the transport of molecules.

145. (A) Thioesters exhibit less resonance stabilization than oxygen esters, making their hydrolysis more exergonic.
Thioester bonds are significantly more reactive than standard oxygen esters due to their electronic properties. The large sulfur atom does not overlap its orbitals as effectively with the carbonyl group, resulting in less resonance stabilization for the bond. Consequently, the hydrolysis of a thioester is more exergonic, releasing more energy that can be used to drive favorable metabolic reactions, such as those found in the citric acid cycle.

146. (D) Transverse diffusion of lipids is slow without enzyme help.
Membrane asymmetry is maintained because the movement of lipids from one leaflet to the other, known as transverse diffusion or flip-flop, is energetically unfavorable and occurs very slowly. The polar head group must pass through the hydrophobic core of the bilayer, creating a significant energy barrier. This allows cells to keep different lipid compositions on each side, a task assisted by specialized enzymes like flippases and floppases.

147. (D) Both rely directly on the continuous hydrolysis of ATP by the transport protein itself.
Active transport systems move molecules against concentration gradients but differ in their energy sources. Primary active transport directly uses energy from adenosine triphosphate hydrolysis by the transporter itself. In contrast, secondary active transport relies on the energy stored in electrochemical gradients established by primary pumps. Both processes require specific proteins and can move solutes uphill, but only primary transport is a direct consumer of metabolic energy.

148. (B) Epimers
Monosaccharides that are diastereomers and differ in configuration at exactly one chiral center are specifically called epimers. D-erythrose and D-threose are four-carbon sugars that exhibit this relationship. This structural distinction is biochemically significant because enzymes and transporters are highly sensitive to the spatial arrangement of hydroxyl groups, meaning that different epimers often follow distinct metabolic pathways or have different biological fates within the cell.

149. (D) It is a highly branched polysaccharide.
Cellulose is a linear homopolysaccharide composed of D-glucose units linked by beta one-four glycosidic bonds. Unlike storage polymers such as glycogen or starch, cellulose lacks branches, which allows the long chains to align parallel to each other and form strong hydrogen-bonded microfibrils. This structure provides exceptional tensile strength, making it the primary structural component of plant cell walls and one of the most abundant organic molecules.

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150. (B) The average of the pKa values of the two carboxyl groups
For acidic amino acids like glutamate, the isoelectric point is the pH where the molecule has no net charge. This occurs when the positive charge of the amino group is balanced by the negative charges of the carboxyl groups. Because the molecule reaches this state between the deprotonation of its two acidic carboxyl groups, the pI is calculated by taking the average of their two respective pKa values.

151. (A) Steric hindrance between atoms in the polypeptide backbone and side chains
The conformations of a polypeptide backbone are restricted by the spatial requirements of its constituent atoms. Steric hindrance occurs when the electron clouds of non-bonded atoms overlap, creating repulsive forces. These interactions limit the possible ranges for the phi and psi dihedral angles, which are visualized on a Ramachandran plot. These constraints are the fundamental reason why proteins adopt specific secondary structures like alpha-helices and beta-sheets, which are visualized on a Ramachandran plot.

152. (B) An independently folding structural and functional unit of a polypeptide
A protein domain is a distinct, compact portion of a polypeptide chain that can fold into a stable structure independently of the rest of the protein. Each domain often has a specific functional role, such as binding a ligand or catalyzing a reaction. Large proteins frequently consist of multiple domains, allowing them to perform complex, multi-step tasks. This modular organization is a key feature of protein evolution and function.

153. (C) Solid
Saturated fats consist of fatty acid chains with no double bonds, allowing them to adopt a straight conformation. This shape enables the molecules to pack closely together, maximizing van der Waals interactions and resulting in a relatively high melting point. Consequently, fats with a high proportion of saturated fatty acids are typically solid at room temperature, which is characteristic of many animal fats used for energy storage.

154. (D) It contains a highly polar, large hydrophilic head group.
Cholesterol is an amphipathic molecule essential for maintaining the physical properties of animal cell membranes. It consists of a rigid four-ring steroid nucleus and a short hydrocarbon tail, both of which are highly hydrophobic. Its only polar part is a single small hydroxyl group. By inserting into the bilayer, cholesterol modulates fluidity across various temperatures and serves as the primary metabolic precursor for the synthesis of steroid hormones.

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155. (A) $A = T$ and $G \equiv C$
In the standard B-DNA double helix, complementary nitrogenous bases are held together by specific hydrogen bonds. Adenine pairs with thymine through two hydrogen bonds, while guanine pairs with cytosine through three hydrogen bonds. This highly specific pairing ensures the accurate replication of genetic information and contributes to the overall stability of the DNA molecule. The three bonds in GC pairs make those regions more resistant to denaturation.

156. (B) The presence of an anticodon loop and an amino acid acceptor stem
Transfer RNA molecules are essential adapters in protein synthesis, characterized by a unique three-dimensional L-shape derived from a cloverleaf secondary structure. Each tRNA features a specific anticodon loop that pairs with mRNA codons and an acceptor stem where the corresponding amino acid is attached. They also contain various modified bases that enhance their structural stability and ensure the high fidelity of the genetic translation process.

157. (D) Terpenoids
Terpenoids represent a vast and diverse class of plant secondary metabolites constructed from repeating five-carbon isoprene units. This group includes familiar compounds such as menthol, camphor, and carotenoids, which give many plants their characteristic scents and colors. Terpenoids serve critical ecological roles, including defense against herbivores and the attraction of pollinators, and they are synthesized via complex biosynthetic pathways located in both the cytosol and plastids.

158. (B) Decreased synthesis of prostaglandins and thromboxanes
Cyclooxygenase is the key enzyme responsible for converting arachidonic acid into prostaglandins and thromboxanes. Inhibiting this enzyme directly reduces the production of these potent

lipid mediators, which are essential for signaling pain, fever, and inflammation. This mechanism is the primary way that non-steroidal anti-inflammatory drugs work to provide relief from symptoms. Consequently, inhibition of this pathway decreases the localized inflammatory response and alters related physiological functions.

159. (A) IgG
Immunoglobulin G is the most abundant antibody in human serum and plays a vital role in the systemic immune response. It is the only class of immunoglobulin capable of being transported across the placenta from the mother to the fetus. This process provides the newborn with essential passive mobility, protecting it from various pathogens during the first few months of life while its own immune system is still developing.

160. (D) Hydrogen bonds
Hydrogen bonds are highly directional non-covalent interactions that form between a hydrogen atom covalently bonded to an electronegative atom and another electronegative atom. In the DNA double helix, these bonds occur specifically between complementary nitrogenous bases on opposing strands. This precise bonding pattern is fundamental for the specificity of base pairing, allowing for the accurate storage, replication, and transcription of the genetic information contained within the cell.

161. (A) The pH is less than the pKa.
The Henderson-Hasselbalch equation defines the relationship between pH, pKa, and the ratio of conjugate base to weak acid. When the concentration of the weak acid is greater than that of its conjugate base, the log of the ratio becomes negative. Consequently, the calculated pH will be lower than the pKa value of the acid, reflecting a more acidic environment where the protonated form of the buffer dominates.

162. (C) Eukaryotes lack plasma membranes entirely, relying solely on cell walls.
Both eukaryotic and prokaryotic cells are enclosed by a phospholipid plasma membrane that regulates the transport of molecules. Eukaryotes are characterized by internal membrane-bound organelles and a nucleus, whereas prokaryotes generally lack these features and have a simpler structure. While many cells also have a cell wall, it never replaces the essential plasma membrane, which is a universal requirement for maintaining the internal environment of any living cell.

163. (C) Complex (head-tail morphology)
The T4 bacteriophage is a classic example of a virus with complex morphology. Its structure consists of an icosahedral head that houses the double-stranded DNA genome and a contractile tail assembly used to inject the genetic material into the bacterial host. This sophisticated head-tail architecture is specifically designed to facilitate the efficient attachment and penetration of the tough bacterial cell wall during the infection process.

164. (D) Nutrient storage, waste degradation, and turgor maintenance.
The plant vacuole is a multifunctional organelle that occupies a large portion of the cell volume. It serves as a storage site for essential nutrients, pigments, and toxic metabolites while also containing enzymes for the degradation of cellular waste. Crucially, the vacuole maintains turgor pressure by regulating water content, which provides the necessary structural support for the plant and drives cell expansion and overall growth.

165. (A) Cytosolic fraction (soluble proteins and molecules)
Subcellular fractionation uses sequential centrifugation steps at increasing speeds to isolate different cellular components. After several rounds, the final high-speed ultracentrifugation pellets the smallest membrane-bound vesicles, known as microsomes. The remaining liquid portion, called the supernatant, contains the cytosol. This fraction is composed of soluble proteins, metabolic intermediates, and various small molecules that were not part of any pelleted organelle or membrane structure.

166. (D) The overall ΔG° is the arithmetic sum of the ΔG° of individual steps.
In thermodynamics, the overall standard free energy change for a series of coupled reactions is simply the sum of the individual changes for each step. This principle allows cells to drive thermodynamically unfavorable, endergonic reactions by coupling them to highly exergonic processes, such as ATP hydrolysis. As long as the net sum of the free energy changes is negative,

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the entire metabolic pathway can proceed spontaneously.

167. (C) FADH2 - Donates electrons directly to Complex II of the respiratory chain
FADH2 is a key reduced electron carrier produced during the citric acid cycle. Unlike NADH, which donates electrons to Complex I, FADH2 is a prosthetic group that transfers its electrons directly to Complex II of the mitochondrial electron transport chain. This entry point results in fewer protons being pumped across the membrane, meaning that FADH2 contributes less to the total ATP yield than a molecule of NADH.

168. (D) Hydrolysis relieves repulsion between negative phosphate groups.
Adenosine triphosphate is a high-energy compound because its structure contains three closely packed, negatively charged phosphate groups. The electrostatic repulsion between these groups creates significant molecular strain. Hydrolysis of the phosphoanhydride bonds relieves this repulsion and results in products that are more stable due to resonance and better solvation. This large release of free energy is utilized by the cell to drive many essential biological processes.

169. (C) Glycolipids - Facing the intracellular cytosol
The fluid mosaic model describes biological membranes as asymmetrical structures. Glycolipids and glycoproteins are carbohydrate-containing molecules that are found exclusively on the extracellular leaflet of the plasma membrane. They are oriented toward the outside of the cell, where they play critical roles in cell-cell recognition, adhesion, and signaling. They are never found facing the intracellular cytosol in healthy, functional cells under normal physiological conditions.

170. (B) It masks the ion's charge with a hydrophobic outer surface.
Valinomycin is a specialized ionophore that facilitates the transport of potassium ions across hydrophobic lipid bilayers. It functions as a mobile carrier by wrapping around the ion, using its polar groups to coordinate the positive charge while exposing a nonpolar exterior to the membrane lipids. This structural arrangement allows the ion to bypass the energy barrier of the bilayer, effectively increasing the membrane's permeability to that specific ion.

171. (A) An internal carbonyl group (ketone)
Monosaccharides are classified as either aldoses or ketoses based on the position of their carbonyl group. Aldoses, such as glucose, feature an aldehyde group located at the end of the carbon chain. In contrast, ketoses, like fructose, possess a ketone group positioned internally, typically at the second carbon. This structural difference influences the chemical reactivity and metabolic pathways of these sugars within the living cell.

172. (D) A heteropolysaccharide present in plant cell walls
Hemicellulose is a diverse class of heteropolysaccharides found alongside cellulose in the primary and secondary cell walls of plants. Unlike the linear and uniform cellulose, hemicellulose consists of various sugar monomers, such as xylose and mannose, and often features branched structures. It serves as a cross-linking agent that binds cellulose microfibrils together, contributing significantly to the overall strength, flexibility, and structural integrity of the plant cell wall.

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173. (B) Methionine
Methionine and cysteine are the two standard sulfur-containing amino acids used in protein synthesis. While cysteine features a reactive sulfhydryl group that can form covalent disulfide bridges to stabilize protein structure, methionine contains a thioether group. This thioether linkage is relatively unreactive and does not allow for the formation of disulfide bonds. Instead, methionine often serves as the starting amino acid during the initiation of translation in most organisms.

174. (A) Conformations corresponding to common secondary structures like alpha-helices and beta-sheets
The clustered regions on a Ramachandran plot represent the dihedral angles that are sterically allowed and energetically favorable for the polypeptide backbone. These areas correspond to the regular, repeating structures that proteins commonly adopt, such as right-handed alpha-helices and both parallel and antiparallel beta-sheets. By mapping these angles, researchers can identify these secondary structural elements and validate the overall quality of proposed protein structural models.

175. (D) Hydrophobic interactions occurring at the subunit interfaces
The quaternary structure of multi-subunit proteins is primarily stabilized by non-covalent forces that occur at the interfaces between individual polypeptide chains. Hydrophobic interactions are particularly dominant, as nonpolar side chains aggregate to minimize their exposure to the surrounding aqueous environment. This hydrophobic effect, supplemented by hydrogen bonds and ionic interactions, ensures that the subunits assemble into a stable, functional complex like hemoglobin or many regulatory enzymes.

176. (C) Saturated fatty acids have higher melting points due to greater van der Waals interactions.
Saturated fatty acids possess straight hydrocarbon chains that allow them to pack tightly together in an orderly fashion. This close proximity maximizes the van der Waals interactions between adjacent molecules, resulting in higher melting points. In contrast, unsaturated fatty acids contain double bonds that introduce kinks, preventing close packing and weakening intermolecular forces. This explains why saturated fats are usually solid at room temperature while unsaturated fats are liquid.

177. (D) Ceramides
Ceramides are the core structural units of all sphingolipids and consist of a long-chain amino alcohol called sphingosine. A fatty acid is attached to the amino group of the sphingosine backbone through an amide bond. Ceramides play essential roles in maintaining the skin's barrier function and serve as signaling molecules in processes like cell differentiation and apoptosis. They are also precursors for more complex sphingolipids like sphingomyelin and various glycolipids.

178. (B) A-DNA is wider and more compressed than B-DNA.
A-DNA and B-DNA are two distinct right-handed double-helical forms of DNA. B-DNA is the standard conformation found in living cells under physiological conditions. A-DNA occurs when DNA is dehydrated and is characterized by a wider diameter and a shorter, more compressed distance along the helical axis. Additionally, the base pairs in A-DNA are tilted significantly relative to the axis, unlike the nearly perpendicular arrangement in the B-form.

179. (C) They are purely composed of protein.
Ribozymes are a unique class of ribonucleic acid molecules that possess intrinsic catalytic activity. Unlike traditional enzymes, which are proteins, ribozymes use their complex three-dimensional RNA structure to accelerate chemical reactions such as RNA splicing and peptide bond formation. This discovery fundamentally changed our understanding of biological catalysis and supports the hypothesis that RNA may have preceded proteins as both genetic material and catalysts in early life.

180. (B) Mediating interactions with the environment, such as defense and attraction
Plant secondary metabolites are diverse chemical compounds that are not directly involved in growth or reproduction but are essential for survival. They play critical ecological roles, including defending the plant against pathogens and herbivores through toxicity or repellency. Others function to attract pollinators or seed dispersers by providing color or scent. These compounds allow plants to effectively interact with and adapt to their complex environmental surroundings and biological competitors.

181. (D) Long-term maintenance of bone density
Eicosanoids are a family of potent local signaling molecules, including prostaglandins and leukotrienes, derived from polyunsaturated fatty acids. They are primarily involved in the regulation of localized physiological responses such as inflammation, fever, blood pressure, and blood clotting. Unlike systemic hormones like estrogen or parathyroid hormone, eicosanoids are generally not associated with the long-term maintenance of bone density, which is governed by different endocrine and metabolic pathways.

182. (B) Macrophage
Macrophages are specialized white blood cells that serve as primary defenders in the innate immune system. They are characterized by their ability to perform phagocytosis, a process in which they engulf and digest large particulate matter, pathogens, and cellular debris. Beyond clearing infections, macrophages also function as antigen-presenting cells, signaling to the adaptive immune system that a foreign invader is present and initiating a more specific immune response.

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183. (B) Ionic interactions - Electrostatic attraction between fully charged groups
Non-covalent interactions are essential for the stability and specificity of biological molecules. Ionic interactions, or salt bridges, occur between functional groups that carry full and opposite electrical charges. These electrostatic forces are stronger than van der Waals interactions and play critical roles in stabilizing protein structures and mediating the binding of substrates to enzymes. Their strength is significantly influenced by the local environment, particularly the presence of water or other ions.

184. (D) Phosphate buffer
The phosphate buffer system is a vital physiological buffer that operates primarily within the intracellular fluid. It consists of dihydrogen phosphate as the weak acid and monohydrogen phosphate as the conjugate base. Because its pKa is near physiological pH, it is highly effective at resisting pH changes inside cells, where metabolic processes frequently produce acidic or basic byproducts. This system is also important in the renal tubule for buffering urine.

185. (D) The cell region where the genetic material is localized.
In prokaryotic cells, the genetic material is not enclosed by a nuclear membrane. Instead, it is found in an irregularly shaped, non-membrane-bound region called the nucleoid. This area contains the genomic DNA, usually a single circular chromosome, along with various proteins and RNA molecules that assist in DNA packaging and gene expression. The nucleoid allows for the direct coupling of transcription and translation, which is a hallmark of prokaryotic biology.

186. (B) Uncoating is always required for bacteriophages.
The replication cycle of viruses involves several key steps: attachment, penetration, uncoating, biosynthesis, maturation, and release. While uncoating is essential for animal viruses to release their genome from the capsid inside the host cell, most bacteriophages do not undergo this step. Instead, they inject their naked genetic material directly through the tough bacterial cell wall while the protein capsid remains attached to the exterior of the host cell.

187. (B) Synthesis of complex lipids and detoxification of xenobiotics
The smooth endoplasmic reticulum is a specialized organelle lacking attached ribosomes. It is the primary site for the biosynthesis of various complex lipids, including phospholipids and steroids. Additionally, it plays a critical role in the detoxification of potentially harmful lipid-soluble drugs and metabolic waste products. In certain cells, it also serves as a storage site for calcium ions, which are released to trigger diverse physiological and signaling responses.

188. (B) Particles move through a gradient until they reach a position where their density matches that of the surrounding medium.
Density gradient centrifugation, specifically the isopycnic method, separates particles based on their unique buoyant densities. A medium with a varying density is created in a centrifuge tube, and the sample is spun at high speeds. Each component migrates through the gradient until it reaches its equilibrium position, where its density equals that of the medium. This allows for the high-resolution separation of organelles and molecules with very similar physical properties.

189. (A) It increases.
The Second Law of Thermodynamics states that the total entropy of an isolated system always increases over time during any spontaneous process. In biological terms, this means that every chemical reaction or physical change results in a net increase in the disorder of the universe. While living organisms can create order within themselves by organizing molecules, they do so by releasing heat and increasing the entropy of their surroundings.

190. (A) It relates the equilibrium potential of an ion to its concentration gradient across a membrane.
The Nernst equation is a fundamental principle used to determine the electrical potential required to balance the chemical driving force of a specific ion gradient. By calculating the equilibrium potential for ions like sodium or potassium, scientists can understand how cells establish their resting membrane potentials. This equation is essential for studying the physiology of excitable cells, such as neurons and muscle fibers, during signaling and transport.

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191. (B) Adenosine triphosphate (ATP)
Adenosine triphosphate is the universal energy currency of the cell, acting as a central intermediate that links energy-releasing reactions to energy-consuming processes. Its high phosphoryl-transfer potential arises from the instability of its phosphoanhydride bonds. When these bonds are hydrolyzed, a significant amount of free energy is released, which the cell captures and utilizes to drive unfavorable metabolic reactions, mechanical work, and active transport across biological membranes.

192. (B) The diverse array of integral and peripheral proteins embedded in or attached to the membrane
The fluid mosaic model describes the structure of biological membranes as a flexible lipid bilayer containing a variety of components. The "mosaic" aspect refers to the heterogeneous mixture of different proteins that are either embedded within the bilayer or loosely attached to its surface. These proteins perform diverse functions, including transport, signaling, and cell recognition, and they move laterally within the fluid lipids, contributing to the membrane's dynamic and multifunctional nature.

193. (A) It transports molecules faster but is subject to saturation (V_{max}) at high solute concentrations.
Facilitated diffusion and simple diffusion both move molecules down concentration gradients without energy input. However, facilitated diffusion utilizes specific membrane proteins, which allows for much faster transport of polar or large molecules. Because the number of transport proteins is finite, the rate of transport eventually reaches a maximum velocity when all carriers are occupied. This saturation property distinguishes it from simple diffusion, where the rate increases linearly with concentration.

194. (A) C-1
In the cyclic structure of an aldohexose, the first carbon atom is designated as the anomeric carbon. This carbon atom is the original carbonyl carbon from the linear chain and becomes a new chiral center upon ring formation. The spatial arrangement of the hydroxyl group attached to this carbon determines whether the molecule is in the alpha or beta anomeric form, which is a critical feature for its chemical reactivity and bonding.

195. (A) Glycogen
Glycogen is a highly branched polysaccharide that serves as the primary form of energy storage in animals and fungi. It is composed of glucose units and is primarily stored in the liver and skeletal muscles. Its branched architecture allows for rapid enzymatic breakdown into glucose when the body requires a quick supply of metabolic fuel. In contrast, starch is the storage polymer for plants, while cellulose provides structural support.

196. (B) Histidine
Histidine is an essential amino acid with a unique imidazole side chain. Its pKa is approximately six point zero, which is relatively close to the physiological pH of seven point four. This property allows histidine to easily switch between protonated and deprotonated states, making it a versatile participant in enzyme catalysis and an effective buffer in biological fluids. It is often found at the active sites of enzymes and within hemoglobin molecules.

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197. (B) Hydrogen bonding between backbone amide and carbonyl groups
Secondary structures like alpha-helices and beta-sheets are regular folding patterns of the polypeptide chain. These structures are stabilized primarily by hydrogen bonds that form between the carbonyl oxygen and the amide hydrogen of the peptide backbone. Because these interactions involve the constant parts of the amino acids rather than the variable side chains, they allow diverse sequences of proteins to adopt these stable and common structural motifs.

198. (C) It is a completely irreversible process in all proteins.
Protein denaturation involves the loss of a protein's functional three-dimensional shape due to heat or chemical treatment. While it disrupts non-covalent interactions and secondary/tertiary structures, it does not break the primary peptide bonds. Interestingly, denaturation is not always irreversible; some proteins can spontaneously refold into their native, active state when the denaturing agent is removed. This suggests that the information for correct folding is encoded in the primary amino acid sequence.

199. (B) It possesses one or more carbon-carbon double bonds in its chain.
Unsaturated fatty acids are characterized by the presence of one or more double bonds within their hydrocarbon tails. These double bonds usually adopt a cis-configuration, which introduces a permanent kink or bend in the chain. This structural feature prevents the molecules from packing tightly together, resulting in weaker intermolecular forces and lower melting points. Consequently, unsaturated fats are typically liquid oils at room temperature, which influences the fluidity of biological membranes.

200. (A) They act as bidirectional regulators of membrane fluidity.
Sterols like cholesterol are critical components of animal cell membranes that function to maintain optimal fluidity across varying environmental temperatures. By interacting with the fatty acid tails of phospholipids, they prevent the membrane from becoming too fluid at high temperatures and too rigid at low temperatures. This bidirectional regulation ensures that the membrane remains semi-permeable and that embedded proteins can function correctly under diverse physiological conditions.

201. (A) Base-pair roll, tilt, and twist
While B-DNA is generally described as a regular helix, its structure actually exhibits subtle, sequence-dependent variations. These localized changes are described by parameters such as base-pair roll, tilt, and twist, which reflect the relative orientation of adjacent base pairs. These geometric fluctuations are biologically significant because they can influence the binding affinity of specific proteins, such as transcription factors, to particular regions of the genetic material.

202. (A) mRNA carries coding information to the ribosome; rRNA is a structural and catalytic component of the ribosome.
Messenger RNA and ribosomal RNA perform distinct and essential roles in the process of translation. mRNA serves as the temporary blueprint that carries the genetic sequence from DNA to the ribosome. In contrast, rRNA is a permanent and abundant part of the ribosome itself. It provides the structural scaffold and the actual catalytic activity required to join amino acids together, illustrating the diverse functional capabilities of RNA molecules.

203. (A) Tannins (Phenolics)
Tannins are a group of complex phenolic compounds found in many plants, known for their ability to bind and precipitate proteins. They serve as potent defensive chemicals against herbivores by making plant tissues unpalatable or indigestible. Their structure is characterized by multiple phenol rings with numerous hydroxyl groups, which allows them to form strong interactions with biological molecules. Tannins are significant secondary metabolites in both plant ecology and human food science.

204. (C) 20 carbons, 4 double bonds
Arachidonic acid is a crucial polyunsaturated fatty acid with a twenty-carbon chain and four cis-double bonds. It is primarily found esterified in the phospholipids of cell membranes. Upon release by phospholipase enzymes, it serves as the central metabolic precursor for the synthesis of eicosanoids, a class of potent signaling molecules including prostaglandins and leukotrienes that regulate inflammation, immunity, and various other vital physiological processes.

205. (B) The variable regions (Fab) of the heavy and light chains
The specific binding affinity of an immunoglobulin for its antigen is determined by the variable regions located at the tips of the antibody molecule. These regions, found on both the heavy and light chains, form a unique binding site called the paratope. The amino acid sequence in these areas varies significantly between antibodies, allowing the immune system to generate millions of different molecules that can specifically recognize and bind to diverse foreign antigens.

206. (A) Steric repulsion between electron clouds
Van der Waals forces represent weak attractive and repulsive interactions between all atoms. As two atoms approach each other, they initially experience an attraction due to fluctuating electron clouds. However, if they get too close, their electron clouds begin to overlap, leading to powerful steric repulsion. This repulsion sets a minimum distance, known as the van der Waals contact distance, which prevents atoms from occupying the same space.

207. (B) An increase in dissolved CO_2 (pCO_2)
The bicarbonate buffer system is the primary mechanism for maintaining blood pH. According

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to the Henderson-Hasselbalch equation, the pH is determined by the ratio of bicarbonate to dissolved carbon dioxide. When the level of carbon dioxide increases, the concentration of the acidic component of the buffer rises. This shift causes the pH of the blood to decrease, leading to a condition known as respiratory acidosis, which can occur during hypoventilation.

208. (B) Mitochondria perform cellular respiration; chloroplasts perform photosynthesis.
Mitochondria and chloroplasts are specialized energy-converting organelles in eukaryotic cells. Mitochondria are found in almost all eukaryotes and are responsible for cellular respiration, where they break down nutrients to produce ATP. Chloroplasts are specific to plants and algae and perform photosynthesis, using light energy to synthesize organic molecules from carbon dioxide and water. Both organelles possess their own DNA and double membranes, reflecting their evolutionary origin as independent bacteria.

209. (D) Prophage - A virion actively releasing from a cell
A prophage is a bacteriophage genome that has integrated into the host bacterial chromosome and exists in a dormant state. It is replicated along with the host's DNA but does not produce new viruses or lyse the cell during this lysogenic phase. In contrast, a virion is a complete, infective viral particle outside the cell. The active release of new viruses occurs during the lytic cycle, which eventually destroys the host.

210. (B) Mitochondrial matrix
The mitochondrial matrix is the central, fluid-filled compartment enclosed by the inner membrane. It houses a variety of essential enzymes, including those responsible for the citric acid cycle and the oxidation of fatty acids. Additionally, the matrix contains the organelle's own circular DNA, ribosomes, and the machinery required for its unique gene expression. This compartmentalization ensures that the metabolic intermediates of respiration are concentrated near the site of energy production.

211. (C) Isopycnic density gradient centrifugation
Isopycnic density gradient centrifugation is a high-resolution separation technique that isolates particles based on their specific buoyant densities. A gradient is established in a tube, and the sample is spun until each component reaches a position where its density matches the surrounding medium. This method is particularly effective for separating organelles or molecules that have similar sizes but different densities, such as different types of membrane vesicles or DNA variants.

212. (B) It is thermodynamically favorable (spontaneous).
In biological thermodynamics, a negative value for the change in Gibbs free energy signifies that a reaction is exergonic and thermodynamically favorable. This means the process can occur spontaneously under specified conditions, releasing free energy that can be used to perform work. It is important to note that a negative free energy change indicates only the direction and feasibility of the reaction, not the speed at which it actually proceeds.

213. (A) The tendency of a chemical species to be reduced, measured under standard conditions
Standard reduction potential is a measure of the affinity of a molecule for electrons compared to a standard reference electrode. Species with high, positive potentials are strong oxidizing agents and are easily reduced by accepting electrons. In contrast, those with negative potentials are strong reducing agents. This parameter is essential for understanding the direction of electron flow in metabolic redox reactions, such as those in the mitochondrial electron transport chain.

214. (A) The chain of three phosphate groups linked by phosphoanhydride bonds
The high phosphoryl group transfer potential of ATP is primarily due to the chemical properties of its two phosphoanhydride bonds. The three phosphate groups are negatively charged at physiological pH, resulting in strong electrostatic repulsion. Breaking these bonds through hydrolysis relieves this repulsion and produces more stable molecules. This significant release of free energy allows ATP to act as the primary donor of energy for various endergonic reactions within the cell.

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215. (C) The membrane tends to transition to a more rigid, gel-like state.
The physical state of biological membranes is highly temperature-dependent. As the temperature decreases, the kinetic energy of the lipid molecules drops, and the hydrocarbon tails pack more closely together. This leads to

a phase transition where the membrane shifts from a fluid, liquid-crystalline state to a more rigid, ordered gel-like state. This transition can significantly impair the function of membrane proteins and transporters, which require a fluid environment to operate effectively.

216. (D) The glucose-Na+ symporter system in the intestinal epithelium.
Secondary active transport moves solutes against their concentration gradients by utilizing the energy stored in electrochemical gradients. The glucose-sodium symporter is a classic example, where the downhill movement of sodium ions into the cell drives the uphill accumulation of glucose. The sodium gradient is initially established by the sodium-potassium ATPase, a primary active transporter. This mechanism allows the intestinal cells to efficiently absorb nutrients even when they are present at low concentrations.

217. (A) D-isomer
In sugar chemistry, the D and L designations refer to the stereochemistry of the chiral carbon furthest from the carbonyl group. In a standard Fischer projection, if the hydroxyl group on this reference carbon points to the right, the molecule is classified as a D-isomer. If it points to the left, it is an L-isomer. Most biologically relevant monosaccharides, such as glucose and ribose, occur naturally in the D-configuration within living organisms.

218. (B) Starch contains α-glycosidic bonds; cellulose contains β-glycosidic bonds.
Starch and cellulose are both glucose polymers but serve very different biological roles due to their glycosidic linkages. Starch consists of glucose units joined by alpha one-four bonds, which create a helical structure that is easily digested by enzymes for energy. Cellulose uses beta one-four bonds, resulting in long, straight chains that form rigid fibers through hydrogen bonding. This makes cellulose an ideal structural component for cell walls that is resistant to breakdown.

219. (D) It is highly soluble in non-polar solvents.
At the isoelectric point, an amino acid has no net electrical charge because the number of positive and negative groups is equal. This zwitterionic state is highly polar, which typically makes the molecule least soluble in water and leads to its precipitation. However, being highly polar also means it remains insoluble in non-polar solvents. At this specific pH, the lack of a net charge also prevents the molecule from migrating in an electric field.

220. (A) Beta-turn
A beta-turn is a common secondary structure motif that allows a polypeptide chain to make a sharp reversal in direction. It typically consists of four amino acid residues and is stabilized by a hydrogen bond between the first and fourth residues. These turns are essential for connecting consecutive strands in antiparallel beta-sheets and for the overall compact folding of globular proteins, allowing them to adopt their functional three-dimensional shapes.

221. (B) Entropy-driven, due to the increased conformational freedom of the polypeptide chain
Protein unfolding, or denaturation, is primarily driven by a significant increase in the conformational entropy of the polypeptide chain. When a protein is heated, the weak interactions that maintain its native, ordered state are disrupted. The chain then explores a vast number of disordered conformations, which is thermodynamically favorable. This entropic gain overcomes the loss of stabilizing bonds, resulting in the spontaneous transition from a folded to an unfolded state at higher temperatures.

222. (A) Numbering starts from the carboxyl carbon as C-1.
In the delta system of fatty acid nomenclature, the carbon atoms are numbered sequentially starting from the carboxyl end of the molecule. The carboxyl carbon itself is designated as carbon one. This system is used to specify the exact positions of double bonds along the chain. For example, a double bond at the ninth carbon from the carboxyl group would be indicated as being at position delta nine in the fatty acid's name.

223. (A) sn-glycerol-3-phosphate
Glycerophospholipids are the primary structural lipids of biological membranes. Their core structure consists of a glycerol-three-phosphate backbone. Two fatty acid chains are esterified to the first and second carbons of the glycerol, providing a hydrophobic region. The third carbon is linked to a phosphate group, which is further attached to a polar head group. This amphipathic arrangement is fundamental for the

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spontaneous formation of the stable lipid bilayers that enclose all living cells.

224. (A) A-DNA
A-DNA is a right-handed double-helical conformation of DNA that is favored under conditions of low humidity or high dehydration. It is characterized by having approximately eleven base pairs per turn, making it wider and more compressed than the standard B-DNA form. The base pairs in A-DNA are also tilted and displaced away from the helical axis. This structural variant is relevant in some DNA-protein complexes and in certain double-stranded RNA structures.

225. (B) tRNA
Transfer RNA molecules are unique among cellular RNAs due to their high content of chemically modified nitrogenous bases. One of the most common modifications is the conversion of uridine to pseudouridine, which involves a rearrangement of the glycosidic bond. These modified bases are essential for stabilizing the characteristic three-dimensional L-shape of the tRNA molecule and for ensuring its precise interaction with the ribosome and aminoacyl-tRNA synthetases during the protein synthesis process.

226. (A) Deterrence against herbivores and pathogens due to their toxicity
Alkaloids are a diverse class of nitrogen-containing secondary metabolites that serve as powerful chemical defenses in many plants. Because of their toxicity and bitter taste, they act as effective deterrents against herbivory by various animals and help protect the plant from infection by pathogenic microbes. Many alkaloids, such as nicotine and caffeine, have evolved specifically to interfere with the nervous systems or metabolic processes of the organisms that would otherwise consume the plant.

227. (C) Prostaglandins - Contain a five-membered carbon ring derived from arachidonic acid
Prostaglandins are a subclass of eicosanoids characterized by a unique twenty-carbon structure that includes a five-membered cyclopentane ring. They are synthesized from the polyunsaturated fatty acid arachidonic acid through the cyclooxygenase pathway. This specific structural feature is essential for their diverse signaling functions. Prostaglandins act as local hormones, mediating essential physiological processes such as inflammation, blood flow regulation, and the induction of smooth muscle contraction in various tissues throughout the body.

NODIA

228. (A) Helper T-cells (CD4+)
Helper T-cells, identified by their CD4 receptors, are the central coordinators of the adaptive immune system. Upon recognizing antigens presented by other cells, they become activated and secrete a wide range of cytokines. These signaling molecules stimulate the activity of B-cells to produce antibodies and enhance the destructive power of cytotoxic T-cells and macrophages. By orchestrating these diverse responses, helper T-cells ensure that the body mounts an effective and appropriate defense against specific pathogens.

229. (B) The hydrophobic effect driven by water entropy
The lack of mixing between oil and water is explained by the hydrophobic effect. When nonpolar oil molecules are in water, they disrupt the hydrogen-bonding network of the solvent, forcing water molecules into an ordered state. Aggregation of the oil molecules minimizes the surface area in contact with water, which releases the solvent molecules and increases the system's total entropy. This spontaneous process is the same thermodynamic force that drives protein folding and membrane formation.

230. (A) Logarithm of the ratio of conjugate base to weak acid
The Henderson-Hasselbalch equation is a fundamental mathematical relationship used to calculate the pH of a buffer solution. It states that the pH is equal to the pKa of the weak acid plus the common logarithm of the ratio of the conjugate base concentration to the weak acid concentration. This logarithmic relationship explains why buffers are most effective near their pKa and how relatively large changes in concentration ratios produce only small changes in pH.

231. (B) Membrane-bound organelles
Eukaryotic cells are distinguished by their internal compartmentalization, which is achieved through the presence of various membrane-bound organelles. These specialized structures allow for the spatial separation of diverse and

often incompatible biochemical processes, such as protein synthesis in the endoplasmic reticulum and degradation in lysosomes. This organization ensures that specific enzymes and substrates are concentrated where they are needed, enhancing metabolic efficiency and allowing for sophisticated regulation of cellular activities.

232. (C) They commonly possess a lipid envelope derived from the bacterial host membrane.
Bacteriophages are viruses that specifically infect bacteria and are generally composed of a protein capsid surrounding a nucleic acid genome. While many animal viruses possess a lipid envelope derived from the host cell membrane, this feature is very rare among bacteriophages. Most phages have complex protein structures designed to penetrate the rigid bacterial cell wall. They reproduce through either the lytic cycle, causing cell death, or the lysogenic cycle, where they remain dormant within the host.

233. (A) Lysosome
The lysosome is the primary degradative organelle in eukaryotic cells, containing a diverse array of hydrolytic enzymes. It is responsible for breaking down large extracellular macromolecules internalized via endocytosis, as well as obsolete or damaged cellular components through a process called autophagy. By maintaining an internal acidic environment, lysosomes ensure that these enzymes function optimally while preventing accidental damage to the rest of the cell if they were to leak into the neutral cytosol.

234. (A) They identity the purity and presence of specific organelle fractions.
Marker enzymes are proteins that are exclusively or primarily localized within a specific cellular organelle. During the process of subcellular fractionation, researchers measure the activity of these enzymes to track the distribution of organelles across different fractions. The presence and concentration of a marker enzyme, such as acid phosphatase for lysosomes, allow scientists to determine the identity, yield, and purity of the isolated components, ensuring that subsequent biochemical analyses are accurate and specific.

235. (C) Gibbs Free Energy (ΔG)
Gibbs free energy is the most important thermodynamic parameter for predicting the spontaneity of a chemical reaction at constant temperature and pressure. A negative change in free energy indicates that a process is exergonic and can occur spontaneously, while a positive value means the reaction is endergonic and requires energy input. By calculating this value, biochemists can determine the feasibility and direction of metabolic pathways under the specific conditions found within a living cell.

236. (A) Its affinity for electrons relative to a standard hydrogen electrode
Standard reduction potential is an intrinsic property of a chemical species that quantifies its tendency to gain electrons. It is measured under standard conditions relative to a reference hydrogen electrode. A more positive value signifies a higher affinity for electrons, meaning the molecule is a stronger oxidizing agent. This parameter is essential for determining the direction of electron transfer in redox reactions, as electrons naturally flow from species with lower potentials to those with higher potentials.

237. (A) Hydrolysis of ATP is coupled to an endergonic reaction to make the overall process exergonic.
Thermodynamic coupling is a fundamental strategy in metabolism where an energetically unfavorable, endergonic reaction is linked to a highly favorable, exergonic one. The most common example is the coupling of adenosine triphosphate hydrolysis to various biosynthetic processes. By combining the two reactions, the overall change in free energy becomes negative, allowing the otherwise non-spontaneous process to proceed. This mechanism ensures that the cell can perform essential work and synthesize complex molecules efficiently.

238. (B) Its overall fluidity and thickness
The physical properties of a biological membrane, such as its thickness and fluidity, are primarily determined by the specific composition of its lipids. The length and degree of saturation of fatty acid tails influence how tightly they pack together, while the presence of sterols like cholesterol further modulates these characteristics. By adjusting their lipid profiles, cells can maintain the necessary environment for membrane proteins to function correctly across different temperatures and physiological states.

239. (C) Movement of Ca2+ out of the cytosol into the sarcoplasmic reticulum via the SERCA pump
Primary active transport is a mechanism where molecules are moved against their concentration

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gradient using energy derived directly from the hydrolysis of adenosine triphosphate. The SERCA pump is a classic example, as it uses ATP to move calcium ions from the low-concentration cytosol into the high-concentration sarcoplasmic reticulum. This process is essential for muscle relaxation and for establishing the calcium gradients required for subsequent cellular signaling events and regulated release.

240. (A) The interconversion between alpha-D-glucopyranose and beta-D-glucopyranose
Mutarotation is the process of spontaneous interconversion between the alpha and beta anomeric forms of a sugar when it is dissolved in water. For glucose, this involves the cyclic hemiacetal opening into a linear chain and then re-closing to form the other anomer. Eventually, a dynamic equilibrium is reached between the two configurations, resulting in a characteristic and stable optical rotation for the solution. This property is common to all monosaccharides that can form cyclic structures.

241. (A) Cellulose
Cellulose is the primary structural polysaccharide in plant cell walls, composed of linear chains of glucose units joined by beta one-four glycosidic bonds. These linkages allow the molecules to form long, straight chains that align and aggregate into tough, crystalline microfibrils through extensive inter-chain hydrogen bonding. This unique architecture provides the exceptional tensile strength and rigidity necessary to support the plant's structure and resist mechanical stress and osmotic pressure from the environment.

242. (C) At the pI, the molecule is uncharged and lacks any ionized groups.
The isoelectric point is the specific pH at which a molecule has a net electrical charge of zero. It is important to understand that at this pH, the molecule is not devoid of charge; instead, it exists as a zwitterion with an equal number of positive and negative ionized groups. Because the net charge is zero, molecules at their pI exhibit their lowest solubility in aqueous solutions and will not migrate when placed in an electric field.

243. (A) Alpha-helix
The alpha-helix is a common secondary structure in proteins characterized by a tightly coiled polypeptide backbone. The structure is stabilized by intramolecular hydrogen bonds that form between the carbonyl oxygen of one residue and the amide hydrogen of the residue four positions ahead in the sequence. In this right-handed spiral, the amino acid side chains extend outward from the helical axis, minimizing steric interference and allowing the helix to interact with its surroundings.

244. (D) Quaternary structure
Quaternary structure represents the highest level of protein organization, referring to the specific arrangement and interaction of multiple individual polypeptide chains, called subunits, into a single functional complex. These subunits are held together by non-covalent interactions, such as hydrophobic forces and hydrogen bonds, and sometimes by disulfide bridges. This organizational level allows for sophisticated biological functions, such as cooperative binding in hemoglobin or the regulation of complex enzyme activities through allosteric mechanisms.

245. (A) Increasing chain length increases melting point, while increasing unsaturation decreases it.
The melting point of a fatty acid is influenced by its carbon chain length and degree of unsaturation. Longer chains increase the surface area for van der Waals interactions, leading to higher melting points. Conversely, the introduction of cis-double bonds creates kinks in the chain that prevent tight packing, significantly weakening intermolecular attraction and lowering the melting point. This explains why long-chain saturated fats are solid, while shorter or unsaturated fatty acids are typically liquid at room temperature.

246. (B) Sphingolipids have a long-chain amino alcohol backbone.
Sphingolipids and triacylglycerols differ fundamentally in their structural backbones. Triacylglycerols are composed of three fatty acids esterified to a glycerol molecule. In contrast, sphingolipids are built upon a long-chain amino alcohol called sphingosine. A single fatty acid is attached to the nitrogen atom of sphingosine via an amide bond. This unique backbone is essential for the diverse roles sphingolipids play in membrane structure and cellular signaling, particularly in the nervous system of complex organisms.

NODIA

247. (A) 10.5 base pairs per turn; anti-parallel strands
The standard Watson-Crick model of B-DNA describes a right-handed double helix with two strands running in opposite, antiparallel directions. This structure is characterized by having approximately ten point five base pairs per complete helical turn under physiological conditions. The nitrogenous bases are oriented toward the interior, where they form specific hydrogen bonds, while the sugar-phosphate backbone remains on the exterior. This stable and regular arrangement is fundamental for the storage and faithful replication of genetic information.

248. (A) mRNA
Messenger RNA is the specific class of RNA that serves as the direct template for protein synthesis. During the process of transcription, the genetic information from a specific gene is copied into a complementary mRNA strand. This molecule then travels to the ribosome, where its sequence of codons is read and translated into a specific sequence of amino acids to form a polypeptide chain. mRNA acts as the temporary carrier of information between the DNA and the protein.

249. (B) Cyanogenic glycosides
Cyanogenic glycosides are a specialized group of plant secondary metabolites characterized by a sugar moiety attached to a non-sugar component containing a cyanide group. They are stored in vacuoles and remain harmless until the plant tissue is damaged, which brings them into contact with specific enzymes. This interaction triggers the release of toxic hydrogen cyanide, which acts as a powerful deterrent against herbivores by inhibiting their mitochondrial respiration, thus protecting the plant from consumption and damage.

250. (A) Mediation of localized inflammatory responses
Prostaglandins are potent lipid signaling molecules that act as local hormones to coordinate various physiological processes. Their most prominent role is in the mediation of localized inflammatory responses, where they contribute to symptoms like pain, swelling, and fever. They also regulate blood flow and smooth muscle activity in nearby tissues. Because they are synthesized on demand and rapidly degraded, their effects are precisely restricted to the area of injury or stimulation, providing targeted regulation of cellular behavior.

NODIA

251. (A) They act primarily as phagocytes and antigen-presenting cells.
Macrophages are versatile cells of the immune system that perform several essential functions. As phagocytes, they identify, engulf, and destroy pathogens, cellular debris, and foreign particles. Furthermore, they act as professional antigen-presenting cells by processing these substances and displaying specific fragments on their surface. This presentation is critical for the activation of T-cells, linking the innate and adaptive branches of the immune response and ensuring a coordinated defense against infections and diseased cells.

252. (A) Van der Waals forces
Van der Waals forces are weak, non-specific interactions that occur between all atoms and molecules. They arise from temporary fluctuations in the distribution of electrons, which create transient dipoles that induce similar dipoles in neighboring atoms. Although these forces are much weaker than covalent or ionic bonds, their cumulative effect is significant in biological systems. They contribute to the stabilization of the hydrophobic core of proteins and the specific binding of ligands within enzyme active sites.

253. (A) Its ability to resist changes in pH upon the addition of a strong acid or base
Buffer capacity is a quantitative measure of a solution's ability to maintain a stable pH despite the addition of acids or bases. It depends on the total concentration of the buffering species and the ratio of the weak acid to its conjugate base. A buffer is most effective when the pH is close to its pKa value, where both components are present in significant amounts. This property is crucial for preserving the integrity of biological systems and molecules.

254. (B) It ensures that all enzymes are exposed to identical pH environments.
Eukaryotic compartmentalization involves the use of membrane-bound organelles to create distinct internal environments within the cell. This spatial organization allows different organelles to maintain unique conditions, such as the low pH found in lysosomes compared to the neutral cytosol. By isolating specific pathways,

the cell can prevent incompatible reactions, concentrate necessary enzymes and substrates, and achieve a high degree of metabolic efficiency and regulation that is not possible in a single, uniform cellular space.

255. (C) Maturation (Assembly)
The maturation or assembly phase is a critical stage in the viral replication cycle where the newly synthesized viral components are brought together. During this step, viral genomes are packaged into newly formed protein capsids, and in some cases, the virus acquires an envelope. This process results in the formation of complete, infective virions. Following assembly, these new viruses are ready to be released from the host cell to infect other cells and continue the viral lifecycle.

256. (A) Golgi apparatus
The Golgi apparatus is the primary sorting and shipping center of the eukaryotic cell. It receives newly synthesized proteins from the rough endoplasmic reticulum and subjects them to further modifications, such as the addition of complex sugars. Subsequently, the Golgi accurately packages these molecules into specialized vesicles and directs them to their final destinations, whether they are destined for secretion, insertion into the plasma membrane, or transport to other organelles like the lysosomes.

257. (C) Microsomal fraction
During differential centrifugation, subcellular components are separated by size and density using progressively higher speeds. The nuclear fraction pellets first at low speeds, followed by mitochondria. The microsomal fraction, which consists of small vesicles derived from the fragmented endoplasmic reticulum and other membranes, requires much higher centrifugal forces to sediment. The remaining supernatant, containing the soluble cytosolic components, represents the portion of the cell that does not sediment even at these extreme speeds and forces.

258. (C) The reaction is at equilibrium under standard conditions.
When the standard free energy change of a chemical reaction is zero, it indicates that the system is at equilibrium when all reactants and products are present at standard concentrations. At this state, there is no net driving force for the reaction to proceed in either direction. This thermodynamic parameter provides a reference point for understanding the inherent energetics of metabolic reactions and how the actual concentrations of molecules influence the directionality of processes in the cell.

259. (A) E° - Standard reduction potential
Standard reduction potential is a key thermodynamic parameter used to describe the affinity of a chemical species for electrons. It is measured under standard conditions relative to a reference hydrogen electrode. In metabolic redox reactions, this value determines the direction of electron flow, as electrons naturally move from molecules with lower potentials to those with higher potentials. For example, NAD+ and FAD are important electron carriers that participate in these transfers to support energy production.

260. (B) Its lack of resonance stabilization relative to oxygen esters
The thioester bond in acetyl-CoA is considered a high-energy linkage because it lacks the significant resonance stabilization found in typical oxygen-based esters. The large size of the sulfur atom prevents effective orbital overlap with the carbonyl group, making the bond less stable and more reactive. Consequently, the hydrolysis of this bond releases a large amount of free energy, which is utilized by the cell to drive essential metabolic reactions, such as those in the citric acid cycle.

261. (B) Cholesterol
Cholesterol is a vital component of animal cell membranes that acts as a fluidity buffer. At low temperatures, it prevents the hydrocarbon tails of phospholipids from packing too tightly and solidifying into a rigid state. By disrupting this orderly arrangement, cholesterol ensures that the membrane remains fluid and functional even in cold environments. This property is essential for maintaining the movement of membrane proteins and the overall semi-permeable nature of the cell boundary under diverse thermal conditions.

262. (A) Channel
An ion channel is a specialized type of membrane protein that forms a hydrophilic pore across the lipid bilayer. These proteins allow specific ions to move rapidly down their electrochemical gradient through passive transport. Unlike pumps or transporters, channels do not undergo

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significant conformational changes during each transport event and do not require energy input. This mechanism is essential for fast physiological processes, such as the generation of electrical signals in neurons and muscle cells.

263. (A) Anomers
Anomers are a specific class of isomers found in cyclic monosaccharides that differ in the spatial arrangement of atoms only at the hemiacetal or hemiketal carbon. This carbon atom, known as the anomeric carbon, becomes a new chiral center when the sugar chain closes into a ring. The resulting alpha and beta forms exhibit different physical and chemical properties and can spontaneously interconvert in solution through a process called mutarotation until equilibrium is reached.

264. (B) Peptidoglycan
Peptidoglycan is a complex structural heteropolysaccharide that forms the primary component of the bacterial cell wall. It consists of alternating units of N-acetylglucosamine and N-acetylmuramic acid linked by glycosidic bonds. These polysaccharide chains are further cross-linked by short peptide bridges, creating a tough and rigid meshwork. This structure provides essential mechanical support, protecting the bacterium from osmotic lysis and maintaining its characteristic cell shape in various environments, illustrating the diversity of polysaccharide functions.

265. (A) Lysine
Lysine is a basic amino acid characterized by a side chain that contains a primary amino group. At a neutral physiological pH of approximately seven point four, this side-chain amino group is protonated and carries a full positive charge. This property allows lysine to participate in electrostatic interactions and form salt bridges within protein structures. It is also a frequent site for post-translational modifications, such as acetylation and ubiquitination, which are critical for regulating gene expression.

266. (B) It maps the rotation of the peptide bond itself.
The Ramachandran plot maps the energetically allowed regions for the phi and psi dihedral angles of a polypeptide backbone. It does not map the rotation of the peptide bond itself, as that bond has partial double-bond character and is generally fixed in a planar trans-conformation. The plot identifies areas where steric hindrance between atoms is minimized, allowing for the stable formation of secondary structures like alpha-helices and beta-sheets, which occupy specific regions on the diagram.

267. (A) Loss of three-dimensional structure due to exposure to high heat
Protein denaturation is the process by which a protein loses its native, functional three-dimensional conformation due to external stress, such as excessive heat or chemical denaturants. This process involves the disruption of weak non-covalent interactions and disulfide bridges that maintain the secondary and tertiary structures. Crucially, the primary sequence of amino acids remains intact. Since the function of a protein depends entirely on its specific shape, denaturation typically leads to a complete loss of biological activity.

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268. (A) Linoleic acid
Linoleic acid is an essential polyunsaturated fatty acid represented by the numerical nomenclature eighteen colon two. This indicates a chain of eighteen carbon atoms with two double bonds. The numbers in parentheses, nine and twelve, specify that these double bonds are located at the ninth and twelfth carbons from the carboxyl end of the molecule. As an omega-six fatty acid, linoleic acid must be obtained through the diet and is a precursor for other important signaling lipids.

269. (A) Sterols
Sterols, such as cholesterol, are a unique class of lipids characterized by a core structure consisting of four fused hydrocarbon rings. This rigid, tetracyclic steroid nucleus is highly hydrophobic and allows sterols to integrate into the nonpolar interior of biological membranes. By interacting with the fatty acid tails of phospholipids, sterols play essential roles in modulating membrane fluidity and stability. Additionally, this tetracyclic structure serves as the primary metabolic scaffold for the synthesis of all steroid hormones.

270. (A) GC pairs have three hydrogen bonds and strong stacking.
The stability and melting temperature of DNA are significantly influenced by its base composition. Guanine-cytosine pairs are held

together by three hydrogen bonds, compared to only two in adenine-thymine pairs. Additionally, GC pairs exhibit stronger van der Waals stacking interactions with adjacent bases. These combined forces make GC-rich DNA more resistant to thermal denaturation, meaning that higher temperatures are required to separate the two strands during processes like replication or laboratory procedures like the polymerase chain reaction.

271. (A) Ribozyme
A ribozyme is a specialized RNA molecule that possesses intrinsic enzymatic activity, allowing it to catalyze chemical reactions independently of proteins. Some ribozymes are capable of self-splicing, where they precisely remove segments of their own sequence and rejoin the remaining pieces. This discovery proved that nucleic acids can serve as both genetic blueprints and biological catalysts. This dual role supports the idea that early life may have relied on an RNA-based metabolism before the evolution of more efficient protein enzymes.

272. (A) They contain an aromatic ring bearing one or more hydroxyl groups.
Plant phenolics are a large and chemically diverse group of secondary metabolites. Their defining structural feature is the presence of at least one aromatic ring that is directly bonded to one or more hydroxyl groups. These compounds are primarily synthesized through the shikimate pathway and serve numerous critical roles, including protection against ultraviolet radiation, defense against pathogens and herbivores, and contributing to the structural integrity of the plant through complex polymers like lignin found in wood.

273. (A) Prostaglandin H2
The cyclooxygenase pathway is a critical metabolic sequence that converts free arachidonic acid into various bioactive lipid mediators. The first stable intermediate produced by the action of the cyclooxygenase enzyme is prostaglandin H2. This molecule serves as a central branch point, which is then converted by specific downstream enzymes into various prostaglandins, thromboxanes, and prostacyclins. These end products go on to regulate a wide range of essential physiological processes, including inflammation, blood clotting, and smooth muscle tone.

274. (A) They are synthesized by T-cells.
Immunoglobulins, also known as antibodies, are specialized glycoproteins that play a central role in the adaptive immune system. They are composed of two identical heavy chains and two identical light chains held together by disulfide bonds. Each molecule contains variable domains for antigen binding and constant domains for mediating effector functions. Crucially, immunoglobulins are synthesized and secreted exclusively by plasma cells, which are the activated form of B-cells, rather than by T-cells, which perform other immune roles.

275. (A) Hydrophobic effect
The hydrophobic effect is the primary thermodynamic force driving the spontaneous formation of micelles and lipid bilayers by amphipathic molecules in water. When these molecules aggregate, the nonpolar regions are hidden from the aqueous environment. This process is entropy-driven because it releases water molecules that were previously ordered around the individual nonpolar surfaces, significantly increasing the total disorder of the solvent. This same effect is fundamental to the folding of proteins and the stabilization of all biological membranes.

276. (A) When pH is exactly equal to the pKa of the weak acid
A buffer system is most effective at resisting changes in pH when the concentrations of the weak acid and its conjugate base are equal. According to the Henderson-Hasselbalch equation, this specific condition occurs when the pH of the solution is exactly equal to the pKa value of the acid. In this state, the buffer has an equal capacity to neutralize both added protons and added hydroxide ions, providing maximum stability to the biological or chemical environment.

277. (A) The presence of a highly organized cytoskeleton
Eukaryotic cells are distinguished by their complex internal organization, which includes a highly developed and dynamic cytoskeleton. This network of protein fibers, including microfilaments, microtubules, and intermediate filaments, provides mechanical support, maintains cell shape, and enables various forms of movement. Additionally, the cytoskeleton organizes the spatial arrangement of organelles

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and facilitates intracellular transport. This sophisticated structural framework is essential for the diverse and complex behaviors exhibited by eukaryotic organisms compared to simpler, non-compartmentalized prokaryotic cells.

278. (A) They utilize reverse transcriptase to convert their RNA genome into DNA.
Retroviruses are a unique family of viruses characterized by an RNA genome and a specialized enzyme called reverse transcriptase. Upon entering a host cell, the virus uses this enzyme to transcribe its single-stranded RNA into double-stranded DNA. This viral DNA then enters the host nucleus and integrates into the host's own genome, where it can remain dormant or be used as a template to produce new viral particles. This replication strategy is fundamental to the lifecycle of viruses like HIV.

279. (A) Chloroplast
Chloroplasts are the specialized organelles in plant and algal cells responsible for photosynthesis. They are characterized by a complex internal membrane system composed of flattened, sac-like structures called thylakoids. These thylakoids are arranged in extensive stacks known as grana, which house the photosynthetic pigments and the protein complexes required for capturing light energy. This high surface area is essential for the efficient conversion of solar energy into chemical energy during the light-dependent reactions of the photosynthetic process.

280. (A) Catalase
Catalase is a highly efficient antioxidant enzyme that is primarily localized within peroxisomes in eukaryotic cells. It catalyzes the breakdown of hydrogen peroxide, a toxic byproduct of various metabolic processes, into water and oxygen. Because of its specific localization, catalase serves as a standard biochemical marker for identifying the peroxisomal fraction during cell fractionation experiments. Measuring its activity allows researchers to confirm the presence and assess the purity of peroxisomes isolated from a cell homogenate through centrifugation techniques.

281. (A) Zero
The Third Law of Thermodynamics states that the entropy of a perfectly crystalline substance approaches exactly zero as the absolute temperature reaches zero Kelvin. At this theoretical state, all molecular motion ceases, and the system reaches its minimum possible energy level with perfect order. While absolute zero is physically unattainable, this law provides a fundamental reference point for calculating absolute entropies and for understanding the relationship between temperature, molecular order, and the thermodynamic behavior of matter.

282. (A) It has a highly positive standard reduction potential, signifying a high affinity for electrons.
Oxygen is the ideal final electron acceptor in the mitochondrial electron transport chain because it possesses a highly positive standard reduction potential. This property means that oxygen has a very strong affinity for electrons, allowing it to pull them through the various complexes of the respiratory chain. The large difference in potential between the initial electron donors and oxygen releases a significant amount of free energy, which the cell captures to drive the synthesis of adenosine triphosphate.

283. (A) Thioester bond
Coenzyme A is a critical molecule in metabolism that carries acyl groups, such as the two-carbon acetyl group. These groups are attached to the coenzyme through a high-energy thioester bond, formed between the carboxylic acid of the acyl group and the thiol group of coenzyme A. Thioester bonds are more reactive than standard oxygen esters, making them excellent intermediates for transferring acyl groups to other molecules during pathways like the citric acid cycle and fatty acid synthesis.

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284. (A) Lateral diffusion within a single leaflet
The fluid mosaic model describes biological membranes as dynamic structures where lipids move frequently. Lateral diffusion, the movement of lipids within the same leaflet of the bilayer, occurs extremely rapidly and frequently, allowing for the constant rearrangement of components. In contrast, transverse diffusion, or flip-flop from one leaflet to the other, is a very slow and energetically unfavorable process because the polar head group must pass through the hydrophobic core. This difference ensures both fluidity and structural asymmetry.

285. (A) Secondary active transport
Secondary active transport is a mechanism where the movement of one molecule against its concentration gradient is powered by the

spontaneous, downhill movement of another ion, typically sodium or protons. This process relies on the potential energy stored in the electrochemical gradient that was initially established by a primary active transport pump. By coupling the transport of two different species, the cell can efficiently concentrate nutrients or remove waste products without the direct and immediate consumption of adenosine triphosphate.

286. (A) It is a C-2 epimer of glucose.
Epimers are monosaccharides that differ in their three-dimensional configuration at only one specific chiral carbon atom. D-mannose and D-glucose share an identical structure in all aspects except for the arrangement of the hydroxyl group at the second carbon position. This subtle structural distinction is biologically significant because it determines how each sugar is recognized and metabolized by specific enzymes and transport proteins. Mannose is a common component of various glycoproteins and plays essential roles in cellular glycosylation processes.

287. (A) Chitin
Chitin is a robust structural polysaccharide that serves as the primary component of the fungal cell wall and the exoskeleton of arthropods, such as insects and crustaceans. It is composed of linear chains of N-acetylglucosamine units joined by beta one-four glycosidic bonds. This structural arrangement allows for extensive hydrogen bonding between adjacent chains, resulting in tough, insoluble fibers that provide essential protection, support, and rigidity to the organisms that produce it, much like cellulose does in plants.

288. (A) Phenylalanine
Phenylalanine is an essential amino acid characterized by a nonpolar side chain that contains a bulky, hydrophobic benzyl group. This aromatic ring makes the residue highly insoluble in water and allows it to participate in specialized pi-stacking interactions within protein structures. Phenylalanine is typically buried in the hydrophobic core of folded proteins, where it contributes to overall stability. It also serves as a critical metabolic precursor for the synthesis of other important molecules, including the neurotransmitters dopamine and norepinephrine.

289. (A) Strands run in the same N-to-C direction, leading to distorted, angled hydrogen bonds.
Beta-sheets are common protein secondary structures formed by hydrogen bonds between the backbone of adjacent polypeptide strands. In a parallel beta-sheet, all the strands run in the same amino-to-carboxyl direction. This orientation causes the hydrogen bonds to be slightly angled and distorted rather than straight. Consequently, parallel beta-sheets are generally less stable than antiparallel ones, where the strands run in opposite directions and form linear, optimally aligned hydrogen bonds that are stronger and more resistant to disruption.

290. (A) Spontaneous process driven by entropic gain of bulk water.
The thermodynamics of protein folding is a complex balance between entropy and enthalpy. While the folding of the polypeptide chain into a specific shape involves a decrease in the chain's conformational entropy, the process is overall spontaneous. This is primarily driven by the hydrophobic effect, where nonpolar residues aggregate in the interior. This aggregation releases many water molecules from ordered states, resulting in a large net gain in the entropy of the solvent, which makes the folding process energetically favorable.

291. (A) Liquid
Fatty acids with multiple cis-double bonds are categorized as polyunsaturated. Each double bond introduces a permanent bend or kink in the hydrocarbon chain, which prevents the molecules from packing closely together in an orderly, crystalline arrangement. This disruption of tight packing significantly weakens the van der Waals interactions between the chains, leading to a much lower melting point. As a result, these fats are typically found in a liquid state, as oils, at room temperature and under physiological conditions.

292. (A) Sphingoglycolipids
The human ABO blood group system is defined by specific carbohydrate antigens present on the surface of red blood cells. These antigens are attached to membrane-bound molecules called sphingoglycolipids, where a complex sugar chain is linked to a sphingosine-based lipid backbone. The exact sequence of the sugars in these chains is determined by the presence of specific glycosyltransferase enzymes. These glycolipids

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are essential for cell-cell recognition and are the primary factors that determine compatibility during blood transfusions between individuals.

293. (A) Z-DNA is a left-handed helix with a zig-zag backbone; B-DNA is right-handed.
Z-DNA is a unique structural variant of the DNA double helix that forms under specific conditions, such as high salt concentrations or sequences with alternating purines and pyrimidines. Unlike the standard right-handed B-DNA, Z-DNA is a left-handed helix characterized by a distinctive zig-zag phosphate backbone. It is also narrower and more elongated than the B-form. These structural differences are biologically significant as Z-DNA may be involved in the regulation of gene expression and the relief of torsional stress during transcription.

294. (D) It is primarily responsible for forming the structural matrix of the nucleus.
Transfer RNA molecules are essential components of the protein synthesis machinery. They adopt a characteristic three-dimensional L-shaped structure that allows them to function as adapters in the ribosome. Each tRNA features an anticodon that pairs with mRNA and a specific amino acid attached to its three-prime end. Contrary to structural roles in the nucleus, tRNA's primary function is to deliver the correct amino acids in sequence to the growing polypeptide chain, ensuring the accurate translation of genetic information.

295. (A) Alkaloids
Alkaloids are a vast class of nitrogen-containing plant secondary metabolites that are primarily derived from various amino acid precursors. They are well-known for their diverse and often potent pharmacological effects on the nervous systems and metabolic pathways of animals and humans. Many famous natural products, such as morphine, caffeine, and nicotine, are alkaloids. In nature, these compounds serve primarily as a chemical defense mechanism for plants, deterring herbivores and protecting against infection through their toxic or repellent properties.

296. (A) Cyclooxygenase (COX)
The cyclooxygenase enzyme is responsible for the committed step in the synthesis of prostaglandins and thromboxanes from arachidonic acid. It catalyzes the incorporation of oxygen molecules into the fatty acid chain to form unstable intermediates. This enzyme exists in two main isoforms, COX-1 and COX-2, which perform both constitutive and inducible signaling roles. Because it is a central regulator of inflammation and pain, this enzyme is the primary target for many common non-steroidal anti-inflammatory drugs like aspirin and ibuprofen.

NODIA

297. (A) Helper T-cell ($CD4^+$)
The Human Immunodeficiency Virus specifically infects and destroys helper T-cells, which are identified by the presence of CD_4 receptors on their surface. Since these cells are the central coordinators of the entire immune system, their progressive loss leads to a profound state of immunodeficiency. Without functioning helper T-cells, the body is unable to effectively activate B-cells or cytotoxic T-cells, making the individual highly susceptible to opportunistic infections and certain types of cancer that define the clinical stage of AIDS.

298. (A) Maximization of solvent entropy via the hydrophobic effect
The formation of the lipid bilayer in biological membranes is a spontaneous process driven primarily by the hydrophobic effect. When amphipathic lipid molecules are in an aqueous environment, their nonpolar tails aggregate to minimize contact with water. This aggregation releases many water molecules that were previously constrained in ordered cages around the individual tails. This significant increase in the entropy of the surrounding solvent provides the thermodynamic driving force for the stable assembly of the bilayer structure.

299. (A) $pH = pK_a \pm 1$
In biochemistry, a buffer system is most effective at maintaining a stable pH within a specific range, typically one pH unit above and below its pKa value. This is because both the weak acid and its conjugate base are present in significant concentrations within this window, allowing the system to neutralize both added protons and added hydroxide ions. Outside of this range, one component of the buffer becomes too depleted to provide effective resistance to pH changes, making the system less reliable.

300. (A) Mitochondrion
Mitochondria are double-membrane-bound organelles essential for aerobic respiration and energy production in eukaryotic cells. The inner

membrane is characterized by extensive inward folds known as cristae, which provide a large surface area for the electron transport chain and ATP synthase complexes. This structural arrangement maximizes the capacity for oxidative phosphorylation, leading to the efficient synthesis of adenosine triphosphate molecules. The presence of cristae is a defining morphological feature that distinguishes mitochondria from all other cellular organelles.

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CHAPTER 02
Intermediary Metabolism

2015

1. Which thermodynamic parameter determines the spontaneity of a metabolic reaction under constant temperature and pressure?
(A) Change in enthalpy
(B) Change in Gibbs free energy
(C) Change in entropy
(D) Activation energy

2018

2. In bioenergetics, an endergonic reaction is characterized by which of the following?
(A) It occurs spontaneously without energy input.
(B) It releases heat to the surroundings.
(C) It is strictly catabolic in nature.
(D) It has a positive change in standard free energy.

2004

3. Which of the following high-energy compounds possesses the highest standard free energy of hydrolysis?
(A) Phosphoenolpyruvate
(B) ATP
(C) Glucose-6-phosphate
(D) Pyrophosphate

2011

4. What is the fundamental difference between anabolism and catabolism in metabolic flux?
(A) Anabolism is strictly oxidative, whereas catabolism is reductive.
(B) Catabolism consumes ATP, whereas anabolism generates ATP.
(C) Catabolism is exergonic, whereas anabolism is endergonic.
(D) Anabolism involves the breakdown of complex molecules.

2002

5. How does the concept of metabolic flux apply to a biosynthetic pathway?
(A) The rate of turnover of molecules through the pathway.
(B) The restriction of reactions to equilibrium conditions.
(C) The elimination of the need for high-energy intermediates.
(D) The inhibition of regulatory allosteric enzymes.

2014

6. Which statement accurately describes the role of ATP in coupled reactions?
(A) ATP functions as a primary electron donor in cellular reduction reactions.
(B) ATP provides the necessary structural framework for enzyme active sites.
(C) ATP prevents significant fluctuations in local cellular temperature.
(D) ATP hydrolysis drives thermodynamically unfavorable metabolic reactions.

2018

7. The hydrolysis of thioester bonds in compounds such as Acetyl-CoA releases a large amount of free energy. What is the primary reason for this?
(A) Thioesters exhibit greater resonance stabilization than oxygen esters.
(B) Thioesters lack resonance stabilization compared to oxygen esters.
(C) Thioesters are highly hydrophobic and repel water molecules.
(D) Thioesters have higher activation energies for hydrolysis.

2016

8. Under cellular conditions, the actual free energy change (ΔG) differs from the standard free energy change ($\Delta G^{\circ\prime}$) primarily due to which factor?
(A) The presence of specific catalytic enzymes within the cell.
(B) The maintenance of a constant pH of 7.0 in all compartments.
(C) The actual intracellular concentrations of reactants and products.
(D) The attainment of absolute temperature during standard states.

2006

9. Why is the ATP/ADP ratio crucial for maintaining cellular homeostasis?
(A) It dictates the structural integrity of the cell

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membrane.
(B) It serves as a direct transcriptional regulator for all genes.
(C) It facilitates the transport of lipids across the mitochondrial membrane.
(D) It determines the thermodynamic driving force for energy-requiring processes.

2003

10. Consider the following statements regarding high-energy compounds:
I. Phosphocreatine serves as a readily mobilizable reserve of high-energy phosphates in skeletal muscle.
II. 1,3-bisphosphoglycerate contains a high-energy acyl phosphate bond.
III. AMP has a higher phosphoryl group transfer potential than ATP.
Which of the above statement(s) is/are correct?
(A) I and III
(B) II and III
(C) I, II and III
(D) I and II

2009

11. Which classification best applies to the role of NAD+ in cellular metabolism?
(A) It acts as a primary structural component of biological membranes.
(B) It functions as an electron acceptor in catabolic pathways.
(C) It serves as a permanent prosthetic group in all oxidoreductases.
(D) It is an irreversible inhibitor of metabolic flux.

2011

12. Which of the following represents the most appropriate definition of an amphibolic pathway?
(A) A pathway that solely degrades toxic metabolic byproducts.
(B) A pathway serving both catabolic and anabolic functions.
(C) A pathway restricted to use by anaerobic organisms.
(D) A pathway exclusively involved in signal transduction.

2009

13. Which mechanism primarily regulates flux through metabolic pathways by altering the conformation of a rate-limiting enzyme?
(A) Allosteric control
(B) Competitive inhibition
(C) Non-competitive inhibition
(D) Covalent modification

2012

14. What is the defining characteristic of a rate-limiting enzyme in a metabolic pathway?
(A) It catalyzes a reaction maintained in thermodynamic equilibrium.
(B) It operates strictly during the final step of the pathway.
(C) It catalyzes the slowest, irreversible step of the pathway.
(D) It requires continuous degradation and resynthesis for activity.

2024

15. Phosphorylation is a common form of covalent modification. Which class of enzymes catalyzes the addition of a phosphate group to target proteins?
(A) Phosphatases
(B) Ligases
(C) Isomerases
(D) Kinases

2001

16. In allosteric regulation, a homotropic effector typically acts as what?
(A) An inhibitor binding to the active site
(B) A non-substrate molecule modifying enzyme activity
(C) Both the substrate and an allosteric modulator
(D) A transcription factor for the enzyme's gene

2004

17. Which of the following is an example of regulation by proteolytic cleavage?
(A) Phosphorylation of glycogen phosphorylase
(B) Activation of zymogens in the digestive system
(C) Feedback inhibition of hexokinase by glucose-6-phosphate
(D) Ubiquitination of regulatory proteins

2014

18. How does an allosteric inhibitor typically alter the kinetics of an allosteric enzyme?
(A) It decreases the K_m without affecting $V_{\max}$.
(B) It shifts the sigmoidal kinetic curve to the left.
(C) It converts the sigmoidal curve to a hyperbolic curve.
(D) It shifts the sigmoidal kinetic curve to the right.

NODIA

2023

19. What distinguishes covalent modification from allosteric regulation?
(A) Covalent modification requires the action of secondary enzymes.
(B) Covalent modification is strictly irreversible.
(C) Allosteric regulation involves the making and breaking of strong chemical bonds.
(D) Allosteric regulation is significantly slower than covalent modification.

2010

20. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Hexokinase is considered a key regulatory enzyme in glycolysis, but it is not the primary rate-limiting enzyme.
Reason (R) : The product of the hexokinase reaction, glucose-6-phosphate, can be diverted into multiple pathways other than glycolysis.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2016

21. Which molecule commonly acts as an intracellular indicator of low energy status, thereby activating catabolic enzymes?
(A) AMP
(B) ATP
(C) NADH
(D) FADH2

2003

22. What is the effect of adenylation on glutamine synthetase in bacteria?
(A) It permanently denatures the enzyme.
(B) It acts as an allosteric activator.
(C) It promotes the dissociation of the enzyme into inactive monomers.
(D) It covalently downregulates enzyme activity.

2003

23. Feedback inhibition typically targets which step in a biosynthetic pathway?
(A) The final step yielding the end product
(B) The first committed step of the pathway
(C) A reversible reaction near the middle of the pathway
(D) Every single reaction equally

2023

24. Which of the following covalent modifications involves the attachment of a lipid anchor to a protein?
(A) Glycosylation
(B) Acetylation
(C) Prenylation
(D) Methylation

2018

25. Which enzyme catalyzes the primary rate-limiting and committed step of glycolysis?
(A) Hexokinase
(B) Pyruvate kinase
(C) Aldolase
(D) Phosphofructokinase-1

2013

26. What is the net ATP yield from the conversion of one molecule of glucose to two molecules of pyruvate during aerobic glycolysis?
(A) 1 ATP
(B) 2 ATP
(C) 3 ATP
(D) 4 ATP

2024

27. Under anaerobic conditions in mammalian muscle, what is the metabolic fate of pyruvate?
(A) Oxidation to acetyl-CoA
(B) Reduction to lactate
(C) Conversion to ethanol
(D) Carboxylation to oxaloacetate

2017

28. Which intermediate of glycolysis is split by aldolase into two triose phosphates?
(A) Glucose-6-phosphate
(B) Fructose-1,6-bisphosphate
(C) Fructose-6-phosphate
(D) Phosphoenolpyruvate

2001

29. Which reaction in glycolysis involves a substrate-level phosphorylation?
(A) Conversion of 1,3-bisphosphoglycerate to 3-phosphoglycerate
(B) Conversion of glucose to glucose-6-phosphate
(C) Conversion of 2-phosphoglycerate to phosphoenolpyruvate
(D) Conversion of glyceraldehyde-3-phosphate to 1,3-bisphosphoglycerate

2006

30. Match the glycolytic enzymes in List I with their corresponding regulatory effectors in List II.
List I : (Enzymes)

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P. Hexokinase
Q. Phosphofructokinase-1
R. Pyruvate kinase
S. Glyceraldehyde-3-phosphate dehydrogenase

List II : (Regulatory Effectors)

1. Fructose-2,6-bisphosphate
2. Glucose-6-phosphate
3. Fructose-1,6-bisphosphate
4. NAD+ availability

(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-3, S-4
(C) P-2, Q-3, R-1, S-4
(D) P-4, Q-1, R-2, S-3

2021

31. How does high cellular ATP concentration regulate phosphofructokinase-1 (PFK-1)?
(A) It increases the enzyme's affinity for fructose-6-phosphate.
(B) It promotes the covalent phosphorylation of the enzyme.
(C) It enhances the targeted proteolytic degradation of PFK-1.
(D) It acts as an allosteric inhibitor of the enzyme's activity.

2016

32. What is the biological significance of converting pyruvate to lactate under anaerobic conditions?
(A) To generate additional molecules of ATP via substrate-level phosphorylation.
(B) To consume excess oxygen accumulated within the cellular environment.
(C) To regenerate the NAD^+ required for glycolysis to continue.
(D) To produce metabolic precursors for the downstream synthesis of lipids.

2023

33. Which step of glycolysis is inhibited by fluoride ions?
(A) Phosphoglycerate mutase
(B) Enolase
(C) Hexokinase
(D) Triose phosphate isomerase

2022

34. Which of the following accurately describes the energetics of the hexokinase reaction?
(A) Highly reversible and endergonic
(B) Operates near equilibrium under cellular conditions
(C) Driven by a proton gradient
(D) Highly exergonic and physiologically irreversible

2025

35. What is the primary cause of hemolytic anemia in individuals with a genetic deficiency in red blood cell pyruvate kinase?
(A) The intracellular accumulation of toxic levels of pyruvate.
(B) The depletion of ATP causing failure of the Na+/K+ pump.
(C) The cellular inability to produce sufficient levels of NAD+.
(D) The overproduction of various reactive oxygen species.

2002

36. In pancreatic beta cells, which isozyme serves as a glucose sensor due to its high K_m?
(A) Hexokinase I
(B) Glucokinase (Hexokinase IV)
(C) Hexokinase II
(D) Hexokinase III

2001

37. Which enzyme complex links glycolysis to the TCA cycle by converting pyruvate to acetyl-CoA?
(A) Pyruvate carboxylase
(B) Citrate synthase
(C) Malate dehydrogenase
(D) Pyruvate dehydrogenase

2019

38. The TCA cycle operates strictly under aerobic conditions. What is the primary reason for this?
(A) Oxygen is required to replenish NAD+ and FAD via the electron transport chain.
(B) Oxygen is a direct substrate for the cycle's enzymes.
(C) The cycle generates FADH2, which is toxic without oxygen.
(D) The enzymes of the TCA cycle are rapidly degraded in the absence of oxygen.

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2008

39. Which of the following intermediates is a five-carbon compound in the TCA cycle?
(A) Alpha-ketoglutarate
(B) Citrate
(C) Succinate
(D) Malate

2005

40. Consider the following statements regarding the TCA cycle:
I. Succinate dehydrogenase is embedded in the inner mitochondrial membrane.
II. Isocitrate dehydrogenase catalyzes an

oxidative decarboxylation.
III. The cycle produces exactly one molecule of $FADH_2$ per turn.
IV. Citrate synthase is allosterically inhibited by ATP.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I, II, III and IV
(C) I and IV
(D) III only

2025

41. Which reaction in the TCA cycle involves substrate-level phosphorylation?
(A) Conversion of malate to oxaloacetate
(B) Conversion of alpha-ketoglutarate to succinyl-CoA
(C) Conversion of fumarate to malate
(D) Conversion of succinyl-CoA to succinate

2017

42. How many molecules of NADH are generated in one complete turn of the TCA cycle?
(A) One
(B) Two
(C) Three
(D) Four

2011

43. Which term best describes reactions that replenish TCA cycle intermediates depleted by biosynthetic pathways?
(A) Cataplerotic reactions
(B) Anaplerotic reactions
(C) Amphibolic reactions
(D) Epimerization reactions

2017

44. Which enzyme catalyzes the most important anaplerotic reaction in mammalian liver?
(A) Malic enzyme
(B) Pyruvate carboxylase
(C) Phosphoenolpyruvate carboxykinase
(D) Glutamate dehydrogenase

2005

45. What is the role of the fluoroacetate compound in cellular respiration?
(A) It acts as a suicide substrate, leading to the inhibition of aconitase.
(B) It activates isocitrate dehydrogenase.
(C) It uncouples oxidative phosphorylation.
(D) It directly inhibits the electron transport chain complex I.

2015

46. The conversion of malate to oxaloacetate is highly endergonic ($\Delta G^{\circ\prime}$ is positive). How is this reaction driven forward in the cell?
(A) By coupling the reaction directly with ATP hydrolysis.
(B) By the high concentration of intracellular malate molecules.
(C) By the rapid removal of oxaloacetate by citrate synthase.
(D) By an input of heat energy from the mitochondrial matrix.

2021

47. Which enzyme of the TCA cycle is structurally and functionally analogous to the pyruvate dehydrogenase complex?
(A) Isocitrate dehydrogenase
(B) Succinate dehydrogenase
(C) Malate dehydrogenase
(D) Alpha-ketoglutarate dehydrogenase

2022

48. What is the overall net equation for one turn of the TCA cycle starting from acetyl-CoA?
(A) Acetyl-CoA + 2 NAD^+ + 2 FAD + ADP + Pi → 2 CO_2 + 2 NADH + 2 $FADH_2$ + ATP + CoA
(B) Acetyl-CoA + 4 NAD^+ + GDP + Pi → 2 CO_2 + 4 NADH + GTP + CoA
(C) Acetyl-CoA + 3 NAD^+ + FAD + GDP + Pi → 2 CO_2 + 3 NADH + $FADH_2$ + GTP + CoA
(D) Acetyl-CoA + 3 NAD^+ + FAD → 2 CO_2 + 3 NADH + $FADH_2$ + CoA

2007

49. The hexose monophosphate (HMP) shunt occurs in which cellular compartment?
(A) Mitochondrial matrix
(B) Cytosol
(C) Endoplasmic reticulum
(D) Peroxisomes

2003

50. Select the correct order of enzymes in the oxidative phase of the HMP shunt.
(A) Glucose-6-phosphate dehydrogenase, Transaldolase, Transketolase
(B) Glucose-6-phosphate dehydrogenase, Lactonase, 6-Phosphogluconate dehydrogenase
(C) 6-Phosphogluconate dehydrogenase, Lactonase, Glucose-6-phosphate dehydrogenase
(D) Transketolase, Transaldolase, Glucose-6-

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phosphate dehydrogenase

2021

51. What is the primary biological significance of the NADPH generated by the HMP shunt?
(A) It is used for reductive biosynthesis and antioxidant defense.
(B) It acts as an electron donor for mitochondrial ATP synthesis.
(C) It serves as a primary structural component of nucleic acids.
(D) It regulates systemic blood glucose levels through direct action.

2006

52. Which product of the HMP shunt is an essential precursor for nucleotide biosynthesis?
(A) Erythrose-4-phosphate
(B) Xylulose-5-phosphate
(C) Ribose-5-phosphate
(D) Sedoheptulose-7-phosphate

2025

53. The non-oxidative phase of the HMP shunt consists of reversible reactions. Which enzymes are primarily responsible for these carbon skeleton rearrangements?
(A) Transketolases and transaldolases
(B) Mutases and isomerases
(C) Kinases and phosphorylases
(D) Dehydrogenases and reductases

2019

54. What is the role of thiamine pyrophosphate (TPP) in the HMP shunt?
(A) It acts as a cofactor for glucose-6-phosphate dehydrogenase.
(B) It acts as a cofactor for transaldolase.
(C) It acts as an allosteric inhibitor of the pathway.
(D) It acts as a cofactor for transketolase.

2005

55. In a cell requiring more NADPH than ribose-5-phosphate, what is the fate of the ribose-5-phosphate produced?
(A) It is exported from the cell via specialized transport proteins.
(B) It is channeled back into glycolysis via triose intermediates.
(C) It is converted into glycogen stores within the liver or muscle.
(D) It undergoes oxidative decarboxylation to produce molecules of CO_2.

2008

56. Which condition is associated with a genetic deficiency in glucose-6-phosphate dehydrogenase?
(A) Enhanced resistance to bacterial infections
(B) Severe hypoglycemia during fasting
(C) Hemolytic anemia under oxidative stress
(D) Excessive glycogen accumulation in the liver

2022

57. Which metabolic intermediate links the HMP shunt to the synthesis of aromatic amino acids?
(A) Ribulose-5-phosphate
(B) Sedoheptulose-7-phosphate
(C) Glyceraldehyde-3-phosphate
(D) Erythrose-4-phosphate

2013

58. How is the flux through the HMP shunt primarily regulated?
(A) By the availability of NAD^+
(B) By the concentration of ribose-5-phosphate
(C) By the cellular NADP+/NADPH ratio controlling glucose-6-phosphate dehydrogenase
(D) By covalent modification of transaldolase

NODIA

2024

59. What happens in the HMP shunt when a cell is actively synthesizing DNA but requires little NADPH?
(A) The oxidative phase accelerates to produce more NADPH.
(B) The non-oxidative phase reverses to form ribose-5-phosphate from glycolytic intermediates.
(C) The entire pathway shuts down completely.
(D) Ribose-5-phosphate is degraded to generate ATP.

2002

60. Consider the following statements regarding the HMP shunt:
I. It occurs in the cytosol.
II. It is highly active in adipose tissue and the liver.
III. Transketolase transfers a 2-carbon unit.
IV. The pathway does not generate or consume ATP directly.
V. It is a major source of NADPH for reductive biosynthesis.
Which of the above statement(s) is/are correct?
(A) I, III and V
(B) I, II and IV
(C) I, II, III, IV and V
(D) II, IV and V

2025

61. Gluconeogenesis is defined as the synthesis of glucose from which of the following?
(A) Glycogen strictly
(B) Galactose and fructose
(C) Cellulose and starch
(D) Non-carbohydrate precursors

2006

62. Which enzyme in gluconeogenesis bypasses the irreversible pyruvate kinase reaction of glycolysis?
(A) Fructose-1,6-bisphosphatase
(B) Glucose-6-phosphatase
(C) Pyruvate dehydrogenase
(D) Pyruvate carboxylase and Phosphoenolpyruvate carboxykinase

2025

63. The Cori cycle involves the continuous exchange of metabolites between which two tissues?
(A) Liver and brain
(B) Adipose tissue and kidneys
(C) Intestine and skeletal muscle
(D) Skeletal muscle and liver

2010

64. What is the metabolic function of the Cori cycle?
(A) To convert glucose into fatty acids within the hepatic tissue.
(B) To transport urea from skeletal muscle to the renal system.
(C) To transfer lactate to the liver for conversion back to glucose.
(D) To degrade circulating ketone bodies during periods of starvation.

2014

65. Which of the following cannot serve as a precursor for gluconeogenesis in mammals?
(A) Lactate
(B) Even-chain fatty acids
(C) Glycerol
(D) Alanine

2025

66. Where is the enzyme glucose-6-phosphatase primarily located in the cell?
(A) Cytosol
(B) Mitochondrial matrix
(C) Endoplasmic reticulum membrane
(D) Plasma membrane

2004

67. How many high-energy phosphate bonds (ATP/GTP) are consumed to synthesize one molecule of glucose from two molecules of pyruvate?
(A) Two
(B) Four
(C) Six
(D) Eight

2010

68. Reciprocal regulation ensures that glycolysis and gluconeogenesis do not occur simultaneously in a futile cycle. Which molecule acts as a potent allosteric inhibitor of gluconeogenesis and an activator of glycolysis?
(A) ATP
(B) Citrate
(C) Fructose-2,6-bisphosphate
(D) Acetyl-CoA

2016

69. Which vitamin is required as a prosthetic group for pyruvate carboxylase?
(A) Niacin
(B) Biotin
(C) Thiamine
(D) Riboflavin

2005

70. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : High levels of acetyl-CoA promote gluconeogenesis in the liver.
Reason (R) : Acetyl-CoA is an obligate allosteric activator of pyruvate carboxylase.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

71. During prolonged fasting, the kidneys contribute significantly to gluconeogenesis. What is the primary precursor utilized by the kidney?
(A) Glutamine
(B) Lactate
(C) Glycerol
(D) Propionate

2013

72. Which transport mechanism is essential for moving oxaloacetate from the mitochondria to the cytosol during gluconeogenesis?
(A) The direct diffusion of molecules through oxaloacetate pores.
(B) Conversion to malate or aspartate, then specific transport.

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(C) Active transport via a specialized ATP-driven oxaloacetate pump.
(D) The facilitated cotransport of oxaloacetate with sodium ions.

2017

73. What is the primary physiological function of the glyoxylate cycle in plants and microorganisms?
(A) To generate large amounts of NADPH for biosynthetic use.
(B) To facilitate the net conversion of acetyl-CoA to carbohydrates.
(C) To detoxify glyoxylate accumulated during photorespiration.
(D) To produce significant heat energy during seed germination.

2007

74. Which two unique enzymes are found in the glyoxylate cycle but absent in the TCA cycle?
(A) Citrate synthase and aconitase
(B) Malate dehydrogenase and fumarase
(C) Isocitrate lyase and malate synthase
(D) Alpha-ketoglutarate dehydrogenase and succinyl-CoA synthetase

2011

75. In plants, the glyoxylate cycle occurs primarily in which specialized organelle?
(A) Chloroplast
(B) Mitochondrion
(C) Glyoxysome
(D) Vacuole

2004

76. Isocitrate lyase catalyzes the cleavage of isocitrate into which two molecules?
(A) Glyoxylate and succinate
(B) Malate and acetyl-CoA
(C) Oxaloacetate and acetate
(D) Fumarate and carbon dioxide

2013

77. Why are mammals unable to perform the net synthesis of glucose from even-chain fatty acids?
(A) They lack the enzymes to undergo beta-oxidation.
(B) They lack isocitrate lyase and malate synthase.
(C) They cannot convert oxaloacetate to phosphoenolpyruvate.
(D) They excrete all excess acetyl-CoA as ketone bodies.

2007

78. In the glyoxylate cycle, what happens to the succinate produced by isocitrate lyase?
(A) It is excreted from the cell as a waste product.
(B) It is transported to the mitochondria to enter the TCA cycle.
(C) It condenses with acetyl-CoA to form citrate.
(D) It is directly converted into glucose within the glyoxysome.

NQDIA

2011

79. Malate synthase catalyzes the condensation of glyoxylate with which molecule?
(A) Pyruvate
(B) Succinyl-CoA
(C) Oxaloacetate
(D) Acetyl-CoA

2012

80. Match the cycles/pathways in List I with their characteristic features in List II.
List I : (Cycles/Pathways)
P. TCA cycle
Q. Glyoxylate cycle
R. Cori cycle
S. Gluconeogenesis
List II : (Features)
1. Net synthesis of glucose from acetyl-CoA
2. Decarboxylation of 6-carbon and 5-carbon intermediates
3. Requires biotin for the first step
4. Inter-organ transport of lactate
(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-4, R-1, S-3

2003

81. How does the glyoxylate cycle bypass the decarboxylation steps of the TCA cycle?
(A) By replacing NAD+ with FAD as the primary electron acceptor.
(B) By skipping the oxidative decarboxylation steps of the TCA cycle.
(C) By fixing carbon dioxide back into oxaloacetate via carboxylases.
(D) By utilizing oxygen directly to oxidize specific carbon atoms.

2002

82. Which environmental condition most strongly induces the expression of glyoxylate cycle enzymes in microorganisms like E. coli?
(A) High glucose availability
(B) Anaerobic conditions

(C) Growth on acetate or fatty acids as the sole carbon source
(D) High temperatures

2018

83. The glyoxylate cycle requires cooperation with the TCA cycle and gluconeogenesis to synthesize glucose. Which intermediate ultimately leaves the mitochondria to initiate gluconeogenesis?
(A) Citrate
(B) Acetyl-CoA
(C) Glyoxylate
(D) Malate

2006

84. What is the net yield of the glyoxylate cycle from two molecules of acetyl-CoA?
(A) Two molecules of carbon dioxide
(B) One molecule of glucose
(C) One molecule of oxaloacetate
(D) One molecule of succinate

2016

85. In the mitochondrial electron transport chain (ETC), Complex I is also known by which name?
(A) Cytochrome c oxidase
(B) Succinate-Q reductase
(C) NADH-Q oxidoreductase
(D) Q-cytochrome c oxidoreductase

2013

86. Which mobile electron carrier operates strictly within the inner mitochondrial membrane lipid bilayer?
(A) Cytochrome c
(B) Ubiquinone (Coenzyme Q)
(C) NADH
(D) Plastocyanin

2008

87. The flow of electrons through the ETC is dictated by standard reduction potentials (E). Electrons flow spontaneously in which direction?
(A) From carriers with more negative to more positive potential.
(B) From carriers with higher positive potential to lower positive potential.
(C) Independent of reduction potential, driven primarily by cellular ATP.
(D) From carriers with lower molecular mass to those with higher mass.

2003

88. Which complex of the ETC does NOT pump protons across the inner mitochondrial membrane?
(A) Complex I
(B) Complex III
(C) Complex IV
(D) Complex II

2012

89. How many protons are pumped into the intermembrane space per electron pair transferred from NADH to oxygen?
(A) 4
(B) 6
(C) 10
(D) 12

2008

90. Arrange the following electron carriers of the ETC in the correct sequence of electron flow from NADH.
I. Cytochrome c
II. Complex III
III. Ubiquinone
IV. Complex IV
(A) III → II → I → IV
(B) II → III → I → IV
(C) I → II → III → IV
(D) III → I → II → IV

2022

91. What is the terminal electron acceptor in the aerobic mitochondrial electron transport chain?
(A) Water
(B) Cytochrome c
(C) Oxygen
(D) NAD+

2015

92. Cyanide specifically inhibits which component of the electron transport chain?
(A) Complex I
(B) Complex II
(C) Complex III
(D) Complex IV

2014

93. Cytochrome c carries how many electrons at a time?
(A) One
(B) Two
(C) Three
(D) Four

2008

94. What is the functional consequence of the Q cycle operating in Complex III?
(A) It reduces oxygen to water without the associated pumping of protons.

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(B) It facilitates electron transfer between carriers of different valency.
(C) It synthesizes molecules of ATP directly from the flow of electrons.
(D) It reverses the flow of electrons back towards Complex I of the ETC.

2018

95. Which component of Complex IV is responsible for holding the oxygen molecule during its reduction to water, preventing the release of reactive oxygen species?
(A) Cytochrome a3 and Copper B center
(B) FMN and Iron-sulfur clusters
(C) Cytochrome b and Cytochrome c1
(D) Rieske center

2016

96. Amytal and rotenone are known inhibitors of the ETC. Where do they block electron flow?
(A) Between Complex II and Ubiquinone
(B) Between Complex III and Cytochrome c
(C) Between Complex IV and Oxygen
(D) Between Complex I and Ubiquinone

2003

97. The chemiosmotic theory, proposed by Peter Mitchell, posits that ATP synthesis is driven by what?
(A) A proton-motive force across the inner mitochondrial membrane.
(B) The formation of specific high-energy phosphorylated intermediates.
(C) The direct and simultaneous transfer of electrons to molecules of ADP.
(D) The induction of conformational changes in various membrane lipids.

2008

98. The proton-motive force consists of which two components?
(A) A chemical gradient (ΔpH) and an electrical gradient ($\Delta\psi$)
(B) A sodium gradient and a potassium gradient
(C) An ATP gradient and an ADP gradient
(D) A temperature gradient and a pressure gradient

2019

99. Which subunit of ATP synthase forms the transmembrane proton channel?
(A) F1-alpha
(B) F1-beta
(C) F1-gamma
(D) F0-c ring

2012

100. Consider the following statements concerning the binding change mechanism of ATP synthase:
I. The beta subunits possess the catalytic sites for ATP synthesis.
II. The gamma subunit rotates, causing conformational changes in the alpha-beta hexamer.
III. Protons flow through the F1 domain to drive rotation.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I, II and III

2025

101. What describes the conformational states of the beta subunits in the ATP synthase catalytic cycle?
(A) Open, Closed, Inactive
(B) Open, Loose, Tight
(C) Empty, Half-full, Full
(D) Bound, Unbound, Phosphorylated

2009

102. Oligomycin inhibits oxidative phosphorylation. What is its specific mechanism of action?
(A) It blocks electron flow at Complex IV.
(B) It dissipates the proton gradient.
(C) It blocks the proton channel of the F0 subunit of ATP synthase.
(D) It binds and inactivates the ADP/ATP translocase.

2013

103. How do uncoupling agents like 2,4-dinitrophenol (DNP) affect oxidative phosphorylation?
(A) They inhibit the electron transport chain, effectively stopping oxygen consumption.
(B) They allow protons to bypass ATP synthase, decoupling oxygen use from ATP.
(C) They permanently open the ATP synthase channel, increasing total ATP synthesis.
(D) They inhibit the active transport of pyruvate into the mitochondrial matrix.

2014

104. What is the physiological role of the uncoupling protein 1 (UCP-1, or thermogenin) in brown adipose tissue?
(A) To store energy as fat
(B) To generate heat for non-shivering thermogenesis
(C) To produce excess ATP for muscle contraction

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(D) To synthesize glucose during hibernation

2025

105. Based on current consensus, what is the widely accepted P/O ratio (ATP produced per oxygen atom reduced) for the oxidation of NADH?
(A) 3.0
(B) 2.5
(C) 1.5
(D) 2.0

2015

106. Why does the oxidation of $FADH_2$ yield fewer ATP molecules than the oxidation of NADH?
(A) $FADH_2$ is oxidized strictly within the cytosolic compartment of the cell.
(B) $FADH_2$ has a significantly more negative reduction potential than NADH.
(C) $FADH_2$ acts as a direct inhibitor of the ATP synthase enzyme complex.
(D) Electrons from $FADH_2$ bypass Complex I, resulting in fewer protons pumped.

2005

107. Which mitochondrial transport system is responsible for bringing ADP into the matrix and exporting ATP to the cytosol?
(A) Adenine nucleotide translocase
(B) Phosphate translocase
(C) Malate-aspartate shuttle
(D) Carnitine shuttle

2012

108. In the presence of an uncoupler, what happens to the rate of glycolysis in an aerobic cell?
(A) It remains unchanged regardless of the mitochondrial state.
(B) It significantly decreases due to the resulting buildup of ATP.
(C) It increases to compensate for lower mitochondrial ATP production.
(D) It completely halts due to the rapid depletion of cellular oxygen.

2004

109. Where does the beta-oxidation of long-chain fatty acids primarily occur within a mammalian cell?
(A) Mitochondrial matrix
(B) Cytosol
(C) Endoplasmic reticulum
(D) Lysosomes

2019

110. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Long-chain fatty acids cannot diffuse freely across the inner mitochondrial membrane.
Reason (R) : They require the carnitine shuttle system for transport into the mitochondrial matrix.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2018

111. The activation of a fatty acid prior to beta-oxidation involves the formation of which high-energy intermediate?
(A) Fatty acyl-carnitine
(B) Fatty acyl-CoA
(C) Fatty acyl-AMP
(D) Fatty acyl-phosphate

2005

112. The beta-oxidation of an even-chain saturated fatty acid follows a recurring sequence of four reactions. What are they?
(A) Reduction, Dehydration, Reduction, Condensation
(B) Oxidation, Hydration, Oxidation, Cleavage (Thiolysis)
(C) Oxidation, Dehydration, Oxidation, Thiolysis
(D) Hydration, Oxidation, Hydration, Cleavage

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2019

113. Each cycle of beta-oxidation shortens the fatty acyl chain by how many carbon atoms?
(A) Two
(B) One
(C) Three
(D) Four

2008

114. The complete beta-oxidation of a 16-carbon saturated fatty acid (palmitic acid) yields how many molecules of acetyl-CoA?
(A) 7
(B) 8
(C) 9
(D) 16

2006

115. Beta-oxidation of odd-chain fatty acids results in the generation of acetyl-CoA and one molecule of a three-carbon compound at the final cleavage step. What is this compound?
(A) Pyruvate
(B) Propionyl-CoA
(C) Malonyl-CoA
(D) Acetoacetyl-CoA

2007

116. The three-carbon product from odd-chain fatty acid oxidation is eventually converted into which TCA cycle intermediate?
(A) Oxaloacetate
(B) Citrate
(C) Malate
(D) Succinyl-CoA

2013

117. Oxidation of monounsaturated fatty acids requires an additional enzyme not needed for saturated fatty acids. What is this enzyme?
(A) Enoyl-CoA isomerase
(B) 2,4-Dienoyl-CoA reductase
(C) Propionyl-CoA carboxylase
(D) Acyl-CoA dehydrogenase

2006

118. Polyunsaturated fatty acids, such as linoleic acid, require both an isomerase and which other auxiliary enzyme for complete beta-oxidation?
(A) Enoyl-CoA hydratase
(B) 2,4-Dienoyl-CoA reductase
(C) Methylmalonyl-CoA mutase
(D) Thiolase

2017

119. Very long-chain fatty acids (VLCFAs) are initially oxidized in which cellular organelle before entering the mitochondria?
(A) Golgi apparatus
(B) Peroxisomes
(C) Nucleus
(D) Smooth endoplasmic reticulum

2011

120. Match the enzymes of beta-oxidation in List I with their functions in List II.
List I : (Enzymes)
P. Acyl-CoA dehydrogenase
Q. Enoyl-CoA hydratase
R. beta-Hydroxyacyl-CoA dehydrogenase
S. Thiolase
List II : (Functions)
1. Generates NADH
2. Cleaves a two-carbon fragment as acetyl-CoA
3. Generates $FADH_2$
4. Adds water across a double bond
(A) P-1, Q-4, R-3, S-2
(B) P-3, Q-4, R-1, S-2
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-4, R-1, S-3

2006

121. Where does de novo fatty acid biosynthesis primarily occur in eukaryotic cells?
(A) Cytosol
(B) Mitochondria
(C) Peroxisomes
(D) Endoplasmic reticulum

2006

122. Which enzyme catalyzes the committed, rate-limiting step of fatty acid biosynthesis?
(A) Acetyl-CoA carboxylase
(B) Fatty acid synthase
(C) ATP-citrate lyase
(D) Malic enzyme

2006

123. The conversion of acetyl-CoA to malonyl-CoA requires which vitamin cofactor?
(A) Pyridoxal phosphate
(B) Thiamine pyrophosphate
(C) Biotin
(D) Folic acid

2005

124. How is acetyl-CoA transported from the mitochondria to the cytosol for fatty acid synthesis?
(A) As acetyl-carnitine
(B) As citrate via the citrate transport system
(C) Through direct diffusion
(D) As malate

2002

125. The fatty acid synthase (FAS) complex in mammals is structurally best described as what?
(A) A complex of seven distinct, separable proteins
(B) A multimeric enzyme complex anchored to the inner mitochondrial membrane
(C) A nuclear enzyme regulated by RNA
(D) A single multifunctional polypeptide functioning as a homodimer

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2007

126. What serves as the electron donor (reducing equivalent) during the reductive steps of fatty acid biosynthesis?
(A) NADPH
(B) NADH
(C) FADH2
(D) Ascorbic acid

2007

127. During fatty acid synthesis, growing acyl chains are covalently attached to which component of the FAS complex?
(A) Coenzyme A
(B) Acyl carrier protein (ACP)
(C) Biotin carboxyl carrier protein
(D) Flavin mononucleotide

2007

128. What is the final product released by the mammalian fatty acid synthase complex?
(A) Stearic acid (18:0)
(B) Palmitic acid (16:0)
(C) Arachidonic acid (20:4)
(D) Oleic acid (18:1)

2025

129. Elongation of palmitate to form longer fatty acids occurs primarily in which cellular compartments?
(A) Cytosol and Nucleus
(B) Endoplasmic reticulum and Mitochondria
(C) Golgi apparatus and Lysosomes
(D) Peroxisomes and Cytosol

2010

130. Consider the following statements regarding fatty acid desaturation in mammals:
I. It occurs in the endoplasmic reticulum.
II. It utilizes a membrane-bound mixed-function oxidase system.
III. Mammals cannot synthesize linoleic or linolenic acid because they lack desaturases beyond C-9.
IV. It requires O_2 and NADH or NADPH.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I, II, III and IV
(C) III only
(D) I and IV

2001

131. Acetyl-CoA carboxylase (ACC) is highly regulated. Which molecule acts as its principal allosteric activator?
(A) Palmitoyl-CoA
(B) Citrate
(C) Glucagon
(D) AMP

2023

132. How does phosphorylation by AMP-activated protein kinase (AMPK) affect Acetyl-CoA carboxylase activity?
(A) It activates the enzyme by promoting polymerization.
(B) It inactivates the enzyme, stopping fatty acid synthesis.
(C) It targets the enzyme for ubiquitin-mediated degradation.
(D) It alters the substrate specificity from acetyl-CoA to propionyl-CoA.

2021

133. Ketone bodies are primarily synthesized in the mitochondria of which organ?
(A) Skeletal muscle
(B) Liver
(C) Brain
(D) Heart

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2001

134. Which of the following is NOT a ketone body?
(A) Acetoacetate
(B) Acetyl-CoA
(C) Beta-hydroxybutyrate
(D) Acetone

2006

135. Which enzyme is the rate-limiting step in the synthesis of ketone bodies (ketogenesis)?
(A) Thiolase
(B) HMG-CoA synthase
(C) HMG-CoA lyase
(D) Beta-hydroxybutyrate dehydrogenase

2007

136. What physiological condition most strongly promotes ketogenesis?
(A) A long-term high-carbohydrate, low-fat dietary regimen.
(B) Prolonged fasting or uncontrolled diabetes mellitus states.
(C) The immediate post-prandial state following a large meal.
(D) Intense, short-duration anaerobic exercise at peak capacity.

2008

137. During ketogenesis, HMG-CoA lyase cleaves HMG-CoA into which two products?
(A) Acetoacetate and Acetyl-CoA
(B) Beta-hydroxybutyrate and Acetyl-CoA

(C) Acetoacetyl-CoA and Acetate
(D) Two molecules of Acetyl-CoA

2021

138. Why is the liver unable to utilize ketone bodies for its own energy needs?
(A) It lacks the enzyme beta-hydroxybutyrate dehydrogenase in its matrix.
(B) It completely lacks mitochondria within its specialized hepatocytes.
(C) It lacks the enzyme thiophorase (beta-ketoacyl-CoA transferase).
(D) Ketone bodies act as toxic inhibitors within all hepatic cells.

2004

139. How do extrahepatic tissues, such as the brain and muscle, utilize ketone bodies?
(A) By directly excreting them into the urine through the renal system.
(B) By converting them to acetyl-CoA for entry into the TCA cycle.
(C) By converting them to glucose via the hepatic gluconeogenesis pathway.
(D) By using them as primary precursors for de novo fatty acid synthesis.

2018

140. Select the correct order of enzymes involved in the utilization of beta-hydroxybutyrate in extrahepatic tissues.
(A) Thiophorase, beta-hydroxybutyrate dehydrogenase, Thiolase
(B) beta-hydroxybutyrate dehydrogenase, Thiophorase, Thiolase
(C) Thiolase, Thiophorase, beta-hydroxybutyrate dehydrogenase
(D) Thiolase, beta-hydroxybutyrate dehydrogenase, Thiophorase

2013

141. The characteristic "fruity" breath odor in patients with severe diabetic ketoacidosis is caused by which molecule?
(A) Acetoacetate
(B) Acetone
(C) Beta-hydroxybutyrate
(D) Malonyl-CoA

2007

142. Under starvation conditions, what is the primary biochemical driver that diverts acetyl-CoA towards ketogenesis rather than the TCA cycle?
(A) Depletion of oxaloacetate used for gluconeogenesis.
(B) Allosteric inhibition of citrate synthase by ATP.
(C) Large-scale upregulation of the pyruvate dehydrogenase complex.
(D) Excessive availability of the oxidized cofactor NAD^+.

2008

143. How does the transport of ketone bodies in the blood differ from that of free fatty acids?
(A) Ketone bodies require serum albumin for transport.
(B) Ketone bodies are packaged into chylomicrons.
(C) Ketone bodies are water-soluble and travel freely in the plasma.
(D) Ketone bodies are transported within red blood cells.

2010

144. High levels of ketone bodies in the blood lower its pH, leading to a dangerous condition known as ketoacidosis. Which chemical property of acetoacetate and beta-hydroxybutyrate is responsible for this?
(A) They act as strong bases within the extracellular environment.
(B) They contain hydroxyl groups that rapidly absorb free protons.
(C) They are organic acids that dissociate at physiological pH.
(D) They react directly with bicarbonate to form various toxic adducts.

2004

145. Triglycerides (triacylglycerols) are synthesized by the sequential esterification of fatty acyl-CoAs to which backbone molecule?
(A) Glycerol-3-phosphate
(B) Dihydroxyacetone
(C) Sphingosine
(D) Ceramide

2014

146. Which intermediate is shared between the biosynthetic pathways for triglycerides and glycerophospholipids?
(A) Phosphatidic acid
(B) CDP-diacylglycerol
(C) Mevalonate
(D) Sphingomyelin

2016

147. What strategy do cells use to provide the driving force for the synthesis of complex phospholipids, such as phosphatidylcholine?
(A) Hydrolysis of high-energy ATP to AMP and

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PPi
(B) Utilization of CTP to form activated CDP-intermediates
(C) Direct coupling to the electron transport chain
(D) Utilizing a proton gradient across the ER membrane

2009

148. Which phospholipid is a major component of lung surfactant and critical for reducing alveolar surface tension?
(A) Phosphatidylserine
(B) Dipalmitoylphosphatidylcholine (DPPC)
(C) Phosphatidylinositol 4,5-bisphosphate
(D) Cardiolipin

2005

149. Phosphatidylserine can be synthesized in mammals primarily via which reaction?
(A) De novo synthesis from serine and CDP-diacylglycerol
(B) Base-exchange reaction with phosphatidylethanolamine or phosphatidylcholine
(C) Decarboxylation of phosphatidylinositol
(D) Methylation of phosphatidic acid

2017

150. Consider the following statements regarding sphingolipid biosynthesis:
I. The backbone, sphingosine, is synthesized from palmitoyl-CoA and serine.
II. Ceramide is formed by attaching a fatty acid to sphingosine via an amide bond.
III. Sphingomyelin contains a glycerol backbone.
IV. Gangliosides are sphingolipids that contain sialic acid residues.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, III and IV
(C) II, III and IV
(D) I, II and III

2003

151. Which lipid molecule serves the precursor for all glycosphingolipids?
(A) Phosphatidic acid
(B) Diacylglycerol
(C) Ceramide
(D) Sphingosine-1-phosphate

2001

152. Cardiolipin is a unique phospholipid structurally consisting of what?
(A) Two molecules of phosphatidic acid connected by a glycerol bridge
(B) A ceramide backbone linked to multiple sugars
(C) A cholesterol core attached to a phosphate group
(D) A diacylglycerol linked directly to inositol

2019

153. Which organelle is highly enriched in cardiolipin?
(A) Lysosome
(B) Peroxisome
(C) Inner mitochondrial membrane
(D) Golgi apparatus

2003

154. Plasmalogens are unique ether-linked phospholipids. The synthesis of plasmalogens begins in which organelle?
(A) Endoplasmic reticulum
(B) Mitochondria
(C) Peroxisomes
(D) Cytosol

NODIA

2010

155. Phospholipases cleave phospholipids at specific sites. Which phospholipase releases arachidonic acid from membrane phospholipids for eicosanoid synthesis?
(A) Phospholipase A1
(B) Phospholipase A2
(C) Phospholipase C
(D) Phospholipase D

2013

156. In the synthesis of phosphatidylinositol, which activated intermediate is required?
(A) CDP-diacylglycerol
(B) CDP-choline
(C) UDP-glucose
(D) CDP-ethanolamine

2007

157. Cholesterol is a 27-carbon sterol synthesized entirely from which basic precursor molecule?
(A) Malonyl-CoA
(B) Acetyl-CoA
(C) Propionyl-CoA
(D) Pyruvate

2006

158. The biosynthesis of cholesterol can be broadly divided into stages. Which molecule is the key 6-carbon intermediate formed in the first stage?
(A) Isopentenyl pyrophosphate
(B) Squalene
(C) Mevalonate

(D) Lanosterol

2001

159. Which enzyme catalyzes the major rate-limiting and strictly regulated step in cholesterol biosynthesis?
(A) HMG-CoA synthase
(B) HMG-CoA reductase
(C) Squalene epoxidase
(D) Mevalonate kinase

2004

160. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Statin drugs are highly effective at lowering serum cholesterol levels.
Reason (R) : Statins act as competitive inhibitors of HMG-CoA reductase, halting endogenous cholesterol synthesis.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2017

161. In the isoprenoid pathway, mevalonate is converted into activated 5-carbon isoprene units. What are these units?
(A) Geranyl pyrophosphate and Farnesyl pyrophosphate
(B) Isopentenyl pyrophosphate and Dimethylallyl pyrophosphate
(C) Squalene and Lanosterol
(D) Cholesterol and Ergosterol

2011

162. How many molecules of isopentenyl pyrophosphate (or its isomer) are required to synthesize one molecule of farnesyl pyrophosphate (15 carbons)?
(A) Two
(B) Three
(C) Four
(D) Six

2023

163. The condensation of two molecules of farnesyl pyrophosphate forms which 30-carbon intermediate?
(A) Lanosterol
(B) Squalene
(C) Geranylgeranyl pyrophosphate
(D) Ergosterol

2014

164. What is the first cyclic sterol produced in the cholesterol biosynthesis pathway?
(A) Squalene epoxide
(B) Lanosterol
(C) 7-Dehydrocholesterol
(D) Zymosterol

2019

165. HMG-CoA reductase is transcriptionally regulated by which family of proteins?
(A) SREBPs (Sterol Regulatory Element-Binding Proteins)
(B) PPARs (Peroxisome Proliferator-Activated Receptors)
(C) STATs (Signal Transducers and Activators of Transcription)
(D) NF-kB

2009

166. How does high intracellular cholesterol affect the SREBP pathway?
(A) It promotes the immediate release of SREBP into the cell nucleus.
(B) It retains SREBP in the ER via SCAP and Insig interactions.
(C) It induces the phosphorylation and subsequent activation of SREBP.
(D) It degrades the SREBP gene directly within the genomic sequence.

2003

167. Apart from cholesterol, the isoprenoid pathway provides precursors for the synthesis of which crucial mobile electron carrier?
(A) Ubiquinone (Coenzyme Q)
(B) Cytochrome c
(C) Plastoquinone
(D) Ferredoxin

2016

168. Which process ensures the degradation of HMG-CoA reductase when cellular sterol levels are excessively high?
(A) Autophagy
(B) Ubiquitin-proteasome pathway
(C) Lysosomal degradation
(D) Cleavage by caspases

2016

169. Transamination is the primary reaction for the initial catabolism of most amino acids. This process involves the transfer of an alpha-amino group to which common acceptor molecule?
(A) Alpha-ketoglutarate
(B) Pyruvate

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(C) Oxaloacetate
(D) Acetoacetate

2019

170. Match the transaminases in List I with their characteristic products in List II.
List I : (Transaminases)
P. Alanine
Q. Aspartate
R. Glutamate
S. Tyrosine
List II : (Characteristic Products)
1. Alpha-ketoglutarate
2. Oxaloacetate
3. Pyruvate
4. p-Hydroxyphenylpyruvate
(A) P-3, Q-2, R-1, S-4
(B) P-2, Q-3, R-1, S-4
(C) P-3, Q-1, R-2, S-4
(D) P-1, Q-2, R-3, S-4

2015

171. All aminotransferases require a specific prosthetic group for activity. Which vitamin derivative is this?
(A) Thiamine pyrophosphate (TPP)
(B) Pyridoxal phosphate (PLP)
(C) Biotin
(D) Tetrahydrofolate (THF)

2013

172. The chemical mechanism of transamination involves the temporary formation of which covalent intermediate between the amino acid and PLP?
(A) Thioester
(B) Schiff base (aldimine)
(C) Phosphodiester
(D) Mixed anhydride

2002

173. Following transamination, the collected amino groups exist mainly as glutamate. Which enzyme acts on glutamate to release free ammonia (oxidative deamination)?
(A) Glutamate synthetase
(B) Glutaminase
(C) Glutamate dehydrogenase
(D) Glutamate decarboxylase

2005

174. Glutamate dehydrogenase is unique among enzymes because of what specific cofactor requirement?
(A) It can use either NAD+ or NADP+ as an electron acceptor.
(B) It maintains a strict and absolute requirement for ATP.
(C) It utilizes the cofactor FAD exclusively for its activity.
(D) It requires the presence of PLP for the deamination step.

2010

175. Which amino acid undergoes non-oxidative deamination catalyzed by a dehydratase?
(A) Alanine
(B) Serine
(C) Glutamate
(D) Leucine

2010

176. Serine dehydratase requires PLP as a cofactor and acts on serine to yield ammonia and which alpha-keto acid?
(A) Alpha-ketoglutarate
(B) Oxaloacetate
(C) Pyruvate
(D) Glyoxylate

2011

177. How is ammonia primarily transported from skeletal muscle to the liver in a non-toxic form?
(A) As alanine and glutamine
(B) As free ammonium ions in the blood
(C) As urea
(D) As uric acid

2023

178. In the glucose-alanine cycle, what happens to the alanine once it reaches the liver?
(A) It is excreted into the bile.
(B) It is transaminated back to pyruvate, which is used for gluconeogenesis.
(C) It is directly converted to urea.
(D) It is incorporated into hepatic glycogen.

2002

179. Which enzyme is responsible for synthesizing glutamine from glutamate to transport ammonia safely through the bloodstream?
(A) Glutaminase
(B) Glutamate dehydrogenase
(C) Glutamine synthetase
(D) Asparagine synthetase

2022

180. Certain amino acids are primarily catabolized in extrahepatic tissues rather than the liver. Which group of amino acids is predominantly degraded in skeletal muscle?
(A) Branched-chain amino acids (Valine,

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Leucine, Isoleucine)
(B) Aromatic amino acids
(C) Basic amino acids
(D) Sulfur-containing amino acids

2023

181. The Urea Cycle is the primary mechanism for nitrogen excretion in mammals. Where do the reactions of the Urea Cycle take place?
(A) Partially in the liver mitochondria and partially in the cytosol
(B) Exclusively in the liver cytosol
(C) Exclusively in the liver mitochondria
(D) In the kidneys and liver cytosol equally

2001

182. Which enzyme catalyzes the first, rate-limiting, and committed step of the Urea Cycle?
(A) Carbamoyl phosphate synthetase I
(B) Ornithine transcarbamoylase
(C) Argininosuccinate synthetase
(D) Arginase

2017

183. How many molecules of ATP are consumed in the synthesis of one molecule of carbamoyl phosphate?
(A) One
(B) Two
(C) Three
(D) Four

2002

184. The two nitrogen atoms in a urea molecule are derived from which two sources?
(A) Free ammonia and aspartate
(B) Two molecules of free ammonia
(C) Glutamate and glutamine
(D) Aspartate and alanine

2002

185. In the Urea Cycle, ornithine reacts with carbamoyl phosphate to form which intermediate?
(A) Citrulline
(B) Argininosuccinate
(C) Arginine
(D) Fumarate

2018

186. Which molecule acts as an obligate allosteric activator for Carbamoyl phosphate synthetase I?
(A) N-acetylglutamate
(B) ATP
(C) Citrulline
(D) Arginine

NODIA

2024

187. The cleavage of argininosuccinate by argininosuccinate lyase produces arginine and which other intermediate that connects the Urea Cycle to the TCA cycle?
(A) Malate
(B) Oxaloacetate
(C) Fumarate
(D) Succinate

2012

188. Which enzyme catalyzes the final step of the Urea Cycle, cleaving arginine to yield urea and regenerating ornithine?
(A) Arginase
(B) Argininosuccinase
(C) Urease
(D) Ornithine decarboxylase

2008

189. The interconnection between the Urea Cycle and the TCA cycle is often referred to as the "Krebs bicycle." Which pathway acts as the principal shunt moving intermediates between these cycles?
(A) The Aspartate-Argininosuccinate Shunt
(B) The Malate-aspartate Shunt
(C) The Glycerol-3-Phosphate Shunt
(D) The Citrate-Malate Shunt

2014

190. Consider the following statements regarding the energetics of the Urea Cycle:
I. The synthesis of one urea molecule strictly consumes 3 ATP molecules, equivalent to 4 high-energy phosphate bonds.
II. The regeneration of aspartate requires ATP.
III. The cleavage of argininosuccinate generates ATP.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2018

191. Hyperammonemia can result from a defect in any Urea Cycle enzyme. A defect in which enzyme typically leads to the accumulation of citrulline in the blood (Citrullinemia)?
(A) Carbamoyl phosphate synthetase I
(B) Argininosuccinate synthetase
(C) Ornithine transcarbamoylase
(D) Arginase

2023

192. Which transport system ensures the continuation of the Urea Cycle by returning the regenerated ornithine from the cytosol to the mitochondria?
(A) Ornithine-citrulline antiporter
(B) ATP-dependent ornithine pump
(C) Carnitine shuttle
(D) Malate-aspartate shuttle

2011

193. Amino acids are categorized based on their catabolic end products. A glucogenic amino acid yields intermediates that can enter which pathway?
(A) Gluconeogenesis
(B) Ketogenesis exclusively
(C) Direct lipid biosynthesis
(D) Glycogenolysis

2003

194. Which of the following amino acids is exclusively ketogenic in mammals?
(A) Alanine
(B) Phenylalanine
(C) Tryptophan
(D) Leucine

2024

195. Phenylalanine and tyrosine are both glucogenic and ketogenic. Their degradation yields which two end products?
(A) Pyruvate and Acetyl-CoA
(B) Fumarate and Acetoacetate
(C) Oxaloacetate and Acetoacetate
(D) Succinyl-CoA and Acetyl-CoA

2025

196. The carbon skeleton of aspartate is typically converted to which TCA cycle intermediate during catabolism?
(A) Alpha-ketoglutarate
(B) Succinyl-CoA
(C) Fumarate
(D) Oxaloacetate

2023

197. Which of the following amino acids is considered a non-essential amino acid because it can be synthesized from a glycolytic intermediate (3-phosphoglycerate)?
(A) Serine
(B) Methionine
(C) Threonine
(D) Histidine

2008

198. The alpha-ketoglutarate family of amino acids includes those synthesized from or degraded to alpha-ketoglutarate. Which amino acid is NOT part of this family?
(A) Glutamate
(B) Glutamine
(C) Proline
(D) Asparagine

2017

199. Tetrahydrofolate (THF) is a crucial coenzyme in amino acid metabolism. What is its primary biochemical role?
(A) Transfer of one-carbon units (e.g., methyl, methylene, formyl groups)
(B) Transfer of phosphate groups
(C) Decarboxylation reactions
(D) Oxidation-reduction reactions

2021

200. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : S-Adenosylmethionine (SAM) is a highly potent methyl donor compared to N5-methyltetrahydrofolate.
Reason (R) : The methyl group in SAM is attached to a positively charged sulfonium ion, making it highly reactive.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2025

201. The synthesis of tyrosine requires which essential amino acid as a direct precursor?
(A) Tryptophan
(B) Phenylalanine
(C) Histidine
(D) Methionine

2013

202. Methionine catabolism and the methyl cycle produce homocysteine. High levels of homocysteine are a risk factor for cardiovascular disease. The remethylation of homocysteine back to methionine requires which two vitamins?
(A) Vitamin B12 and Folate
(B) Vitamin C and Vitamin E
(C) Thiamine and Riboflavin
(D) Biotin and Pantothenic acid

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2001

203. Which of the following amino acids belongs to the pyruvate family (synthesized from or degraded directly to pyruvate)?
(A) Alanine
(B) Glutamate
(C) Aspartate
(D) Arginine

2001

204. Branched-chain amino acids (BCAAs) share a common catabolic pathway. What is the first common step for their degradation?
(A) Transamination
(B) Decarboxylation
(C) Hydroxylation
(D) Deamination

2021

205. Amino acids act as precursors for many bioactive amines. The neurotransmitter gamma-aminobutyatic acid (GABA) is synthesized via the decarboxylation of which amino acid?
(A) Glutamate
(B) Glycine
(C) Tyrosine
(D) Tryptophan

2007

206. Catecholamines (dopamine, norepinephrine, and epinephrine) are derived sequentially from which amino acid?
(A) Tyrosine
(B) Tryptophan
(C) Histidine
(D) Arginine

2001

207. Serotonin, a critical neurotransmitter regulating mood and appetite, is synthesized from which precursor?
(A) Phenylalanine
(B) Tyrosine
(C) Glutamate
(D) Tryptophan

2005

208. The vasodilator histamine is produced in mast cells through a reaction requiring PLP. What is this reaction?
(A) Transamination of histidine
(B) Decarboxylation of histidine
(C) Hydroxylation of histidine
(D) Deamination of histidine

2011

209. Porphyrins, the core structures of heme, are synthesized in mammals from which two precursors?
(A) Acetyl-CoA and Alanine
(B) Succinyl-CoA and Glycine
(C) Alpha-ketoglutarate and Glutamate
(D) Propionyl-CoA and Serine

2008

210. Match the bioactive compound in List I with its amino acid precursor in List II.
List I : (Bioactive Compound)
P. Nitric Oxide (NO)
Q. Melanin
R. Creatine
S. Niacin (Vitamin B_3)
List II : (Amino Acid Precursor)
1. Arginine, Glycine, Methionine
2. Tryptophan
3. Arginine
4. Tyrosine
(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-3, Q-4, R-2, S-1
(D) P-1, Q-4, R-3, S-2

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2024

211. The polyamines spermidine and spermine are essential for DNA packaging and cell growth. They are synthesized from which amino acid precursor?
(A) Ornithine
(B) Lysine
(C) Histidine
(D) Proline

2019

212. What is the role of S-adenosylmethionine (SAM) in polyamine biosynthesis?
(A) It provides the methyl group.
(B) It acts as an allosteric inhibitor of ornithine decarboxylase.
(C) It provides the carbon backbone for ornithine.
(D) It donates an aminopropyl group after being decarboxylated.

2015

213. Creatine phosphate serves as a rapid energy reserve in muscle. Its biosynthesis begins in the kidney and finishes in the liver. Which three amino acids are required to synthesize creatine?
(A) Arginine, Glycine, Methionine
(B) Glutamate, Aspartate, Alanine
(C) Lysine, Arginine, Histidine

(D) Serine, Glycine, Methionine

2011

214. The biosynthesis of heme involves multiple steps spanning the mitochondria and cytosol. Which enzyme catalyzes the first, rate-limiting step?
(A) delta-Aminolevulinate (ALA) synthase
(B) Uroporphyrinogen I synthase
(C) Ferrochelatase
(D) Porphobilinogen synthase

2008

215. The synthesis of thyroid hormones (T3 and T4) involves the iodination of which amino acid residues on the protein thyroglobulin?
(A) Histidine
(B) Tyrosine
(C) Phenylalanine
(D) Tryptophan

2023

216. Nitric oxide (NO) is a potent signaling molecule regulating vascular tone. Which enzyme synthesizes NO, and what byproduct is produced alongside it?
(A) NO synthase; producing Citrulline
(B) Arginase; producing Urea
(C) Nitrate reductase; producing Glutamine
(D) Nitrite oxidase; producing Aspartate

2022

217. In the de novo synthesis of purine nucleotides, the purine ring is assembled directly on which foundational molecule?
(A) 5-Phosphoribosyl-1-pyrophosphate (PRPP)
(B) Ribose-5-phosphate
(C) Inosine monophosphate (IMP)
(D) Orotic acid

2006

218. Which amino acids contribute atoms directly to the purine ring during its de novo synthesis?
(A) Glutamate, Aspartate, Alanine
(B) Glycine, Aspartate, Glutamine
(C) Serine, Glycine, Methionine
(D) Arginine, Histidine, Lysine

2014

219. What is the first fully formed purine nucleotide in the de novo pathway?
(A) Inosine monophosphate (IMP)
(B) Adenosine monophosphate (AMP)
(C) Guanosine monophosphate (GMP)
(D) Xanthosine monophosphate (XMP)

2001

220. Consider the following statements regarding pyrimidine biosynthesis:
I. The pyrimidine ring is assembled before being attached to PRPP.
II. Carbamoyl phosphate synthetase II (CPS II) is the rate-limiting enzyme in mammals.
III. Aspartate provides the majority of the atoms in the pyrimidine ring.
IV. Uridine monophosphate (UMP) is the first fully formed pyrimidine nucleotide.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I, II, III and IV
(C) II, III and IV
(D) I, III and IV

2004

221. How does Carbamoyl phosphate synthetase II (cytosolic) differ from CPS I (mitochondrial)?
(A) CPS II uses glutamine as a nitrogen donor and does not require N-acetylglutamate.
(B) CPS II utilizes free ammonia as a nitrogen source.
(C) CPS II is involved in the Urea Cycle.
(D) CPS II is allosterically activated by UTP.

2008

222. The salvage pathways recycle free purine and pyrimidine bases. Which enzyme converts hypoxanthine and guanine back to IMP and GMP, respectively?
(A) Hypoxanthine-guanine phosphoribosyltransferase (HGPRT)
(B) Adenine phosphoribosyltransferase (APRT)
(C) Purine nucleoside phosphorylase (PNP)
(D) Xanthine oxidase

2014

223. Deoxyribonucleotides (dNTPs) are essential for DNA replication. Which enzyme is responsible for the reduction of ribonucleotides to deoxyribonucleotides?
(A) Ribonucleotide reductase
(B) Thymidylate synthase
(C) Nucleoside diphosphate kinase
(D) DNA polymerase

2004

224. At what level of phosphorylation does ribonucleotide reductase act on its substrates in most organisms?
(A) Free base
(B) Monophosphate (NMP)
(C) Diphosphate (NDP)
(D) Triphosphate (NTP)

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2015

225. Thymidylate synthase converts dUMP to dTMP. What is the source of the methyl group required for this reaction?
(A) S-Adenosylmethionine (SAM)
(B) N5,N10-Methylenetetrahydrofolate
(C) Biotin
(D) Methylcobalamin

2018

226. Methotrexate is a powerful anti-cancer drug. What is its mechanism of action regarding nucleotide metabolism?
(A) It competitively inhibits the dihydrofolate reductase enzyme.
(B) It inhibits the activity of the ribonucleotide reductase complex.
(C) It directly inhibits the function of the thymidylate synthase enzyme.
(D) It blocks the intracellular synthesis of the PRPP intermediate.

2003

227. Allosteric regulation of ribonucleotide reductase is complex. Which molecule acts as the primary overall activator of the enzyme?
(A) dATP
(B) ATP
(C) dGTP
(D) dTTP

2016

228. Which intermediate in pyrimidine biosynthesis is characterized by an unattached ring structure that builds up in a specific organic aciduria if the subsequent enzyme (UMP synthase) is defective?
(A) Dihydroorotate
(B) Carbamoyl aspartate
(C) Orotate (Orotic acid)
(D) Cytidine

2004

229. The ultimate breakdown product of purine catabolism in humans and other higher primates is what?
(A) Uric acid
(B) Urea
(C) Ammonia
(D) Allantoin

2019

230. Which enzyme catalyzes the final two steps of purine degradation, converting hypoxanthine to xanthine, and xanthine to uric acid?
(A) Adenosine deaminase
(B) Xanthine oxidase
(C) Guanine deaminase
(D) Uricase

2018

231. Gout is characterized by painful joint inflammation. What is the biochemical cause of gout?
(A) Accumulation of urea crystals in joints
(B) Defective pyrimidine degradation
(C) Hyperuricemia leading to the precipitation of sodium urate crystals
(D) Overproduction of lactic acid

2012

232. Allopurinol is commonly prescribed to treat gout. How does allopurinol function?
(A) It acts as a competitive inhibitor and suicide substrate for xanthine oxidase.
(B) It increases the renal excretion of uric acid directly.
(C) It enhances the activity of HGPRT.
(D) It rapidly degrades uric acid to allantoin in the blood.

2022

233. Lesch-Nyhan syndrome is a severe neurological disorder characterized by self-mutilation and hyperuricemia. It is caused by a near-complete deficiency of which salvage enzyme?
(A) Adenine phosphoribosyltransferase (APRT)
(B) Hypoxanthine-guanine phosphoribosyltransferase (HGPRT)
(C) Xanthine oxidase
(D) Ribonucleotide reductase

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2001

234. Why does a deficiency in HGPRT lead to a massive overproduction of uric acid?
(A) It leads to the direct allosteric activation of xanthine oxidase.
(B) It prevents salvage, leading to excess PRPP and de novo synthesis.
(C) It blocks the enzymatic conversion of uric acid to allantoin.
(D) It shifts the pyrimidine degradation products into the purine pathway.

2018

235. Severe combined immunodeficiency (SCID) can be caused by a defect in purine catabolism. Which enzyme deficiency is responsible for this form of SCID?
(A) Adenosine deaminase (ADA)
(B) Purine nucleoside phosphorylase (PNP)
(C) AMP deaminase
(D) Uricase

2002

236. How does an ADA deficiency specifically lead to the destruction of T and B lymphocytes?
(A) The accumulation of uric acid damages cellular lipid membranes.
(B) Accumulation of dATP inhibits ribonucleotide reductase activity.
(C) It causes rampant and completely uncontrolled DNA replication.
(D) It leads to the direct denaturation of cellular immunoglobulins.

2018

237. Pyrimidine catabolism differs significantly from purine catabolism in what fundamental way?
(A) Pyrimidine breakdown yields completely insoluble waste products.
(B) Pyrimidine breakdown pathways do not occur within mammals.
(C) Pyrimidine degradation produces highly water-soluble intermediates.
(D) Pyrimidines are degraded strictly within cellular lysosomes.

2002

238. What is the metabolic fate of the carbon skeletons generated from pyrimidine degradation?
(A) They are converted into cholesterol.
(B) They are converted into Acetyl-CoA and Succinyl-CoA, feeding into the TCA cycle.
(C) They are excreted intact in the urine.
(D) They are utilized exclusively for synthesizing new purines.

2007

239. The degradation of cytosine first requires deamination to form which pyrimidine base?
(A) Uracil
(B) Thymine
(C) Orotate
(D) Dihydrothymine

2014

240. Select the correct order of intermediates in the degradation of AMP to uric acid.
(A) AMP, Adenosine, Inosine, Hypoxanthine, Xanthine, Uric acid
(B) AMP, IMP, Hypoxanthine, Inosine, Xanthine, Uric acid
(C) AMP, Xanthine, Inosine, Hypoxanthine, Uric acid
(D) AMP, Adenosine, Hypoxanthine, Inosine, Xanthine, Uric acid

2014

241. Metabolic integration ensures that tissues meet their specific energy demands. In the well-fed state, the liver predominantly utilizes which metabolic pathway to handle excess glucose?
(A) Gluconeogenesis
(B) Glycogenesis and lipogenesis
(C) Ketogenesis
(D) Glycogenolysis

2010

242. During prolonged fasting (starvation), the brain undergoes a critical metabolic adaptation. What is this adaptation?
(A) It switches entirely to the beta-oxidation of free fatty acids.
(B) It stores large amounts of glycogen to maintain metabolic autonomy.
(C) It upregulates enzymes required to utilize circulating ketone bodies.
(D) It begins utilizing available amino acids as its primary fuel source.

2017

243. Adipose tissue lacks the enzyme glycerol kinase. Therefore, how does it obtain the glycerol-3-phosphate required for triglyceride synthesis during the fed state?
(A) From the direct phosphorylation of glycerol imported from the blood
(B) From the reduction of dihydroxyacetone phosphate (DHAP) generated by glycolysis
(C) From the breakdown of membrane phospholipids
(D) From the glyoxylate cycle

2019

244. Skeletal muscle differs from the liver in its handling of glycogen. Why can't muscle glycogen contribute directly to blood glucose levels?
(A) Muscle lacks the enzyme glucose-6-phosphatase.
(B) Muscle lacks the enzyme glycogen phosphorylase.
(C) Muscle glycogen is chemically distinct and cannot be broken down to monomers.
(D) Muscle cells lack GLUT transporters entirely.

2009

245. In the early stages of fasting (roughly 12-24 hours), what is the primary source of glucose for maintaining blood sugar levels?
(A) Hepatic gluconeogenesis from amino acids
(B) Hepatic glycogenolysis
(C) Muscle glycogenolysis
(D) Renal gluconeogenesis

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2002

246. Which hormone is the principal driver of metabolic changes during the fed state, promoting anabolic pathways?
(A) Glucagon
(B) Epinephrine
(C) Cortisol
(D) Insulin

2016

247. The "glucose-fatty acid cycle" (Randle cycle) describes reciprocal regulation in muscle. When fatty acid oxidation is high, how does it inhibit glucose utilization?
(A) Elevated acetyl-CoA and citrate inhibit specific glycolytic enzymes.
(B) Fatty acids physically block the activity of the GLUT4 transporter.
(C) Ketone bodies act to directly inhibit the hexokinase enzyme.
(D) Beta-oxidation rapidly depletes cellular ATP, stopping glycolysis.

2012

248. Consider the following statements regarding the metabolic profile of the kidney during prolonged starvation:
I. The kidney becomes a major site of gluconeogenesis.
II. Glutamine is utilized to generate alpha-ketoglutarate and ammonia.
III. Ammonia excretion helps buffer the urine against ketoacidosis.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I, II and III
(C) II and III
(D) I and III

2025

249. How do red blood cells (erythrocytes) exclusively generate ATP?
(A) Oxidative phosphorylation
(B) Beta-oxidation of fatty acids
(C) Anaerobic glycolysis ending in lactate
(D) The HMP shunt

2012

250. Match the tissues in List I with their preferred metabolic fuel in the resting, post-absorptive state in List II.
List I : (Tissues)
P. Brain
Q. Resting skeletal muscle
R. Heart muscle
S. Red blood cells
List II : (Preferred Metabolic Fuel)
1. Fatty acids
2. Glucose (exclusively via aerobic pathways)
3. Glucose (exclusively via anaerobic glycolysis)
4. Fatty acids (highly reliant)
(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-4, R-1, S-3

2019

251. Which hormone promotes lipolysis in adipose tissue and gluconeogenesis in the liver during acute stress?
(A) Epinephrine
(B) Insulin
(C) Aldosterone
(D) Thyroxine

2013

252. What role does AMP-activated protein kinase (AMPK) play in the integration of cellular metabolism?
(A) It acts as an energy sensor, switching on ATP-generating pathways.
(B) It acts as an energy sensor, switching on ATP-consuming pathways.
(C) It exclusively regulates gene expression within the cell nucleus.
(D) It is an extracellular hormone that lowers systemic blood glucose.

2014

253. In signal transduction, what defines an agonist?
(A) A molecule that binds to a receptor but prevents signal activation
(B) A ligand that binds to a receptor and triggers a biological response
(C) A molecule that acts as a secondary messenger inside the cell
(D) An enzyme that degrades the ligand

2012

254. G-protein coupled receptors (GPCRs) share a highly conserved structural motif. What is this structural feature?
(A) Seven transmembrane alpha-helices
(B) A single transmembrane beta-barrel
(C) An intracellular kinase domain
(D) An extracellular ligand-gated ion channel

2003

255. When a GPCR binds its ligand, it acts as a guanine nucleotide exchange factor (GEF). What specific action does it perform on the G-protein?
(A) It promotes the exchange of bound GDP for

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GTP on the alpha subunit.
(B) It phosphorylates the G-protein.
(C) It hydrolyzes GTP to GDP on the beta subunit.
(D) It triggers the ubiquitin-mediated degradation of the G-protein.

2009

256. Heterotrimeric G-proteins consist of alpha, beta, and gamma subunits. Which subunit possesses intrinsic GTPase activity?
(A) Alpha
(B) Beta
(C) Gamma
(D) Both Beta and Gamma

2016

257. How is a G-protein signaling cascade normally terminated?
(A) The specific ligand is transported directly into the cell.
(B) The alpha subunit hydrolyzes its bound GTP to the GDP form.
(C) The receptor is rapidly degraded by the cellular proteasome.
(D) The effector enzyme permanently binds to the G-protein complex.

2019

258. Which specific class of G-protein alpha subunit ($G\alpha$) stimulates the effector enzyme adenylate cyclase?
(A) $G\alpha_s$
(B) $G\alpha_i$
(C) $G\alpha_q$
(D) $G\alpha_{12/13}$

2017

259. Cholera toxin causes massive fluid secretion in the intestine leading to severe diarrhea. What is the molecular target and mechanism of this toxin?
(A) It irreversibly activates $G\alpha_s$ by inhibiting its intrinsic GTPase activity.
(B) It acts as an antagonist at the GPCR.
(C) It permanently inactivates adenylate cyclase.
(D) It cleaves the beta subunit of the G-protein.

2009

260. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Receptor tyrosine kinases (RTKs) generally require dimerization for activation.
Reason (R) : Ligand binding induces dimerization, which allows the intracellular kinase domains to cross-phosphorylate (autophosphorylate) each other.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

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2010

261. The insulin receptor is a classic example of which type of receptor?
(A) Receptor tyrosine kinase
(B) GPCR
(C) Ligand-gated ion channel
(D) Nuclear hormone receptor

2011

262. Which family of small, monomeric G-proteins is heavily involved in signaling cell growth and division downstream of RTKs?
(A) Ras
(B) Ran
(C) Rab
(D) Rho

2012

263. Steroid hormones are highly hydrophobic. Where are their primary functional receptors located?
(A) In the cytosol or nucleus, acting as transcription factors
(B) On the outer leaflet of the plasma membrane
(C) Embedded within the plasma membrane
(D) Inside the mitochondrial matrix

2019

264. Phosphodiesterase (PDE) enzymes play a crucial role in regulating signal transduction. What is their function?
(A) They cleave phosphodiester bonds to degrade secondary messengers like cAMP and cGMP.
(B) They synthesize cAMP from ATP.
(C) They phosphorylate target proteins.
(D) They dephosphorylate target proteins.

2013

265. Cyclic AMP (cAMP) functions as a second messenger primarily by activating which downstream target?
(A) Protein kinase A (PKA)
(B) Protein kinase B (PKB/Akt)
(C) Protein kinase C (PKC)
(D) Calmodulin-dependent kinase

2023

266. How does cAMP physically activate its primary target kinase?
(A) By directly phosphorylating the catalytic subunits of the kinase.
(B) By binding to regulatory subunits to free active catalytic subunits.
(C) By acting as a coenzyme within the enzyme's primary active site.
(D) By modifying genomic DNA to express higher levels of the kinase.

2017

267. The effector enzyme phospholipase C (PLC) is activated by which G-protein subunit?
(A) $G\alpha_s$
(B) $G\alpha_q$
(C) $G\alpha_i$
(D) $G\beta\gamma$

2008

268. Phospholipase C cleaves the membrane lipid phosphatidylinositol 4,5-bisphosphate (PIP2) into which two critical second messengers?
(A) Inositol 1,4,5-trisphosphate (IP3) and Diacylglycerol (DAG)
(B) cAMP and cGMP
(C) Phosphatidic acid and Inositol
(D) Arachidonic acid and Lysophospholipid

2018

269. What is the specific cellular function of the second messenger IP3?
(A) It remains in the plasma membrane to anchor protein kinases.
(B) It enters the nucleus to directly initiate gene transcription.
(C) It opens specialized voltage-gated sodium channels in the membrane.
(D) It binds to ER receptors to trigger the release of calcium ions.

2012

270. Diacylglycerol (DAG) acts synergistically with cytosolic calcium to fully activate which enzyme?
(A) Protein kinase C (PKC)
(B) Protein kinase A (PKA)
(C) Adenylate cyclase
(D) Phospholipase A2

2002

271. Calcium acts as a ubiquitous intracellular messenger. It exerts many of its effects by binding to which small, highly conserved regulatory protein?
(A) Calmodulin
(B) Troponin I
(C) Myoglobin
(D) Arrestin

2018

272. How many calcium ions can one molecule of calmodulin bind fully saturated?
(A) One
(B) Two
(C) Three
(D) Four

2022

273. Cyclic GMP (cGMP) is a second messenger involved in vasodilation and visual phototransduction. Which enzyme synthesizes cGMP?
(A) Guanylate cyclase
(B) Adenylate cyclase
(C) Phosphodiesterase type 5
(D) GTPase

2012

274. Consider the following statements concerning NO-cGMP signaling in smooth muscle:
I. Nitric oxide diffuses across membranes and directly binds to soluble guanylate cyclase.
II. Activation of guanylate cyclase increases cGMP levels.
III. cGMP activates Protein kinase G (PKG), leading to muscle relaxation.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I, II and III
(C) II and III
(D) I and III

2006

275. In the visual transduction cascade of the retina, light causes a structural change in rhodopsin. What happens to the second messenger cGMP in response to light?
(A) Its levels drop rapidly due to the activation of a phosphodiesterase.
(B) Its levels increase dramatically due to guanylate cyclase activation.
(C) It is exported out of the photoreceptor cell into the surroundings.
(D) It is converted directly into cAMP within the specialized cell.

2013

276. What characterizes the phenomenon of signal desensitization or adaptation in GPCR pathways?
(A) Continuous exposure to a ligand permanently

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upregulates receptor numbers.
(B) The receptor is bound by beta-arrestin and uncoupled from G-proteins.
(C) The G-protein permanently fuses with the secondary effector enzyme.
(D) The cell completely stops synthesizing the specific signaling ligand.

2022

277. Glycogen storage diseases (GSDs) are a group of inborn errors of carbohydrate metabolism. Von Gierke's disease (GSD Type I) is caused by a deficiency in which enzyme?
(A) Glucose-6-phosphatase
(B) Glycogen phosphorylase
(C) Debranching enzyme
(D) Branching enzyme

2021

278. Pompe's disease (GSD Type II) is unique among glycogenoses because it is fundamentally a lysosomal storage disease. Which enzyme is defective?
(A) Muscle phosphorylase
(B) Liver phosphorylase
(C) Lysosomal alpha-1,4-glucosidase (acid maltase)
(D) Glygogen synthase

2011

279. McArdle's disease (GSD Type V) affects skeletal muscle. Patients typically present with exercise intolerance and muscle cramps. Which enzyme is deficient?
(A) Liver glycogen phosphorylase
(B) Muscle glycogen phosphorylase
(C) Muscle phosphofructokinase
(D) Debranching enzyme

2009

280. Classic galactosemia is a severe genetic disorder characterized by liver damage, cataracts, and intellectual disability if milk is not avoided. It is primarily caused by a deficiency in which enzyme?
(A) Galactokinase
(B) Galactose-1-phosphate uridyltransferase (GALT)
(C) UDP-hexose 4-epimerase
(D) Lactase

2004

281. In classic galactosemia, the accumulation of which toxic metabolite is largely responsible for cataract formation?
(A) Galactitol (Dulcitol)
(B) Galactose-1-phosphate
(C) UDP-galactose
(D) Glucose-6-phosphate

2018

282. Familial hypercholesterolemia (FH) is a genetic disorder of lipid metabolism resulting in severely elevated LDL cholesterol. The most common genetic defect in FH affects which protein?
(A) HMG-CoA reductase
(B) LDL receptor
(C) Apolipoprotein A-I
(D) Lipoprotein lipase

2006

283. Which sphingolipidosis is characterized by the accumulation of GM2 ganglioside in the brain, leading to rapid neurological decline and a "cherry-red spot" on the macula?
(A) Tay-Sachs disease
(B) Gaucher's disease
(C) Niemann-Pick disease
(D) Fabry's disease

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2005

284. Gaucher's disease, the most common lysosomal storage disorder, is caused by a deficiency in which enzyme?
(A) Beta-glucocerebrosidase
(B) Sphingomyelinase
(C) Hexosaminidase A
(D) Alpha-galactosidase A

2025

285. Niemann-Pick disease types A and B result in the massive accumulation of sphingomyelin in the liver, spleen, and brain. Which enzyme is deficient?
(A) Sphingomyelinase
(B) Ceramidase
(C) Arylsulfatase A
(D) Beta-galactosidase

2018

286. Hereditary fructose intolerance is a potentially fatal condition caused by a deficiency in which glycolytic/fructolytic enzyme?
(A) Fructokinase
(B) Aldolase B
(C) Triose kinase
(D) Hexokinase

2002

287. Match the lipid storage disease in List I with its accumulating metabolite in List II.
List I : (Lipid Storage Disease)

P. Tay-Sachs disease
Q. Gaucher's disease
R. Niemann-Pick disease
S. Krabbe disease

List II : (Accumulating Metabolite)

1. Glucocerebroside
2. GM2 Ganglioside
3. Galactocerebroside
4. Sphingomyelin

(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-2, Q-4, R-1, S-3
(D) P-3, Q-1, R-4, S-2

2019

288. Which of the following conditions is an X-linked recessive disorder of sphingolipid degradation, whereas most others are autosomal recessive?
(A) Fabry's disease
(B) Tay-Sachs disease
(C) Gaucher's disease
(D) Metachromatic leukodystrophy

2025

289. Phenylketonuria (PKU) is an inborn error of amino acid metabolism that causes severe intellectual disability if untreated. It is most commonly caused by a defect in which enzyme?
(A) Phenylalanine hydroxylase (PAH)
(B) Tyrosinase
(C) Homogentisate oxidase
(D) Branched-chain alpha-keto acid dehydrogenase

2019

290. In patients with classic PKU, which essential amino acid must be strictly restricted in the diet, and which conditionally non-essential amino acid must be supplemented?
(A) Restrict Phenylalanine; Supplement Tyrosine
(B) Restrict Tyrosine; Supplement Phenylalanine
(C) Restrict Tryptophan; Supplement Niacin
(D) Restrict Methionine; Supplement Cysteine

2014

291. Alkaptonuria is a rare genetic disorder characterized by urine that turns black upon standing and severe arthritis in adulthood. Which intermediate of tyrosine catabolism accumulates in this disease?
(A) Homogentisate
(B) p-Hydroxyphenylpyruvate
(C) Maleylacetoacetate
(D) Dopamine

2025

292. Albinism results from a defect in melanin biosynthesis. The classic oculocutaneous form of albinism is caused by a deficiency in which enzyme?
(A) Tyrosinase
(B) Phenylalanine hydroxylase
(C) Tyrosine aminotransferase
(D) DOPA decarboxylase

2025

293. Maple syrup urine disease (MSUD) is characterized by sweet-smelling urine and severe neurological damage. Which complex of enzymes is deficient in MSUD?
(A) Branched-chain alpha-keto acid dehydrogenase
(B) Alpha-ketoglutarate dehydrogenase
(C) Pyruvate dehydrogenase
(D) Methylmalonyl-CoA mutase

2003

294. In Maple syrup urine disease, which three amino acids (and their alpha-keto acids) accumulate in the blood and urine?
(A) Leucine, Isoleucine, Valine
(B) Phenylalanine, Tyrosine, Tryptophan
(C) Serine, Glycine, Methionine
(D) Lysine, Arginine, Histidine

2021

295. Homocystinuria is an inborn error involving methionine metabolism, leading to lens dislocation, skeletal abnormalities, and thrombosis. The classic form is caused by a deficiency in which enzyme?
(A) Cystathionine beta-synthase
(B) Methionine synthase
(C) Methylenetetrahydrofolate reductase (MTHFR)
(D) S-adenosylhomocysteine hydrolase

2023

296. Classic homocystinuria responds well to high-dose supplementation of a specific vitamin acting as a cofactor for the deficient enzyme. Which vitamin is this?
(A) Pyridoxine (B_6)
(B) Biotin (B_7)
(C) Riboflavin (B_2)
(D) Ascorbic acid (C)

2019

297. Tyrosinemia Type I (hepatorenal tyrosinemia) is a severe disorder causing liver failure and cabbage-like body odor. It is caused by a

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deficiency in the final enzyme of the tyrosine catabolic pathway. What is this enzyme?
(A) Fumarylacetoacetase
(B) Homogentisate oxidase
(C) p-Hydroxyphenylpyruvate dioxygenase
(D) Tyrosine hydroxylase

2004

298. Consider the following statements regarding Phenylketonuria (PKU):
I. Untreated PKU leads to hypopigmentation (fair skin and hair) due to lack of tyrosine.
II. Phenylacetate and phenylpyruvate accumulate and give urine a musty odor.
III. BH4 deficiency can also result in PKU symptoms.
IV. Tetrahydrobiopterin (BH4) is the required cofactor for the reaction.
Which of the above statement(s) is/are correct?
(A) I and II
(B) III only
(C) I, II, III and IV
(D) I and IV

2018

299. Select the correct sequence of accumulating metabolites in the progression of amino acid catabolism defects (from earliest pathway step to latest).
(A) Phenylalanine (PKU) → p-Hydroxyphenylpyruvate (Tyrosinemia II) → Homogentisate (Alkaptonuria) → Fumarylacetoacetate (Tyrosinemia I)
(B) Homogentisate → Phenylalanine → p-Hydroxyphenylpyruvate → Fumarylacetoacetate
(C) Phenylalanine → Homogentisate → p-Hydroxyphenylpyruvate → Fumarylacetoacetate
(D) Fumarylacetoacetate → Homogentisate → p-Hydroxyphenylpyruvate → Phenylalanine

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2025

300. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Patients with Maple syrup urine disease (MSUD) must meticulously control their dietary intake of branched-chain amino acids, but they cannot completely eliminate them.
Reason (R) : Leucine, isoleucine, and valine are essential amino acids required for normal protein synthesis and growth.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

****

ANSWERS

1. (B) Change in Gibbs free energy
Spontaneity in metabolic reactions is determined by the change in Gibbs free energy at constant temperature and pressure. A negative value indicates a spontaneous, exergonic process, while a positive value denotes a non-spontaneous, endergonic reaction requiring energy input. This thermodynamic parameter accounts for both enthalpy and entropy changes, reflecting the energy available to perform useful work in cellular systems.

2. (D) It has a positive change in standard free energy.
Bioenergetic reactions classified as endergonic are characterized by a positive standard free energy change. These processes are not thermodynamically spontaneous and require a net input of energy from the surroundings to proceed. In biological systems, these reactions are frequently coupled with exergonic ATP hydrolysis to overcome the energetic barrier and facilitate essential biosynthetic or mechanical cellular work for survival.

3. (A) Phosphoenolpyruvate
Among biological high-energy phosphate compounds, phosphoenolpyruvate possesses the highest standard free energy of hydrolysis at approximately negative sixty-one kilojoules per mole. This exceptional energy release occurs because the hydrolysis product, pyruvate, undergoes rapid tautomerization from the unstable enol form to the stable keto form. This makes it a potent phosphoryl group donor for generating ATP directly during the glycolysis pathway.

4. (C) Catabolism is exergonic, whereas anabolism is endergonic.
Metabolism is divided into catabolism and anabolism based on energy flow and molecular complexity. Catabolism involves the oxidative degradation of complex nutrients into simpler molecules, releasing energy in an exergonic manner. Conversely, anabolism is an endergonic process utilizing ATP and reducing power to synthesize complex cellular components from simpler precursors. These two pathways are often reciprocally regulated to maintain homeostasis.

5. (A) The rate of turnover of molecules through the pathway.
Metabolic flux refers to the rate at which substrates and intermediates are processed through a specific biochemical pathway over time. It is determined by the activity of rate-limiting enzymes and the availability of substrates or cofactors. In biosynthetic pathways, maintaining an appropriate flux is essential for meeting the cellular demands for specific products while preventing the wasteful accumulation of intermediate metabolites.

6. (D) ATP hydrolysis drives thermodynamically unfavorable metabolic reactions.
Adenosine triphosphate acts as the universal energy currency by coupling its highly exergonic hydrolysis to endergonic cellular processes. By sharing a common intermediate, the energy released from breaking the phosphoanhydride bonds in ATP provides the necessary thermodynamic drive for unfavorable reactions, such as active transport and biosynthesis. This coupling ensures that the overall free energy change for the linked reactions remains negative.

7. (B) Thioesters lack resonance stabilization compared to oxygen esters.
Thioester bonds, such as those found in Acetyl-CoA, release significant free energy upon hydrolysis because they lack the resonance stabilization characteristic of oxygen esters. In an oxygen ester, the lone pair of electrons on the oxygen can overlap with the carbonyl group, whereas the larger sulfur atom in thioesters allows for less effective orbital overlap. This high-energy state facilitates acyl group transfer.

8. (C) The actual intracellular concentrations of reactants and products.
The actual free energy change of a reaction in vivo depends on the standard free energy change adjusted for the actual concentrations of reactants and products. Unlike standard conditions, which assume one molar concentrations, intracellular levels vary significantly and are rarely at

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equilibrium. This concentration dependency allows reactions with a positive standard free energy to proceed forward if product removal is rapid.

9. (D) It determines the thermodynamic driving force for energy-requiring processes.
The ATP/ADP ratio is a critical indicator of the energy status within a cell. A high ratio ensures a large negative free energy change for ATP hydrolysis, providing a potent thermodynamic driving force for biosynthetic and transport reactions. Maintaining this ratio away from equilibrium is essential for homeostasis, as it allows the cell to respond rapidly to changing metabolic and energetic demands.

10. (D) I and II
Phosphocreatine acts as a rapid buffer for ATP levels in muscle by donating its high-energy phosphate group. Similarly, 1,3-bisphosphoglycerate contains a high-energy acyl phosphate bond used for substrate-level phosphorylation. However, adenosine monophosphate has a lower phosphoryl group transfer potential compared to ATP, as it lacks the high-energy phosphoanhydride bonds found in the di- and triphosphate forms of the nucleotide.

11. (B) It functions as an electron acceptor in catabolic pathways.
Nicotinamide adenine dinucleotide serves as a vital coenzyme acting primarily as an electron carrier in catabolic reactions. During the oxidation of nutrients in glycolysis and the citric acid cycle, this molecule accepts two electrons and one proton to become reduced. The resulting reduced form later donates these electrons to the mitochondrial electron transport chain to facilitate oxidative phosphorylation and ATP production.

12. (B) A pathway serving both catabolic and anabolic functions.
An amphibolic pathway is a biochemical route that functions in both the oxidative breakdown of molecules and the provision of precursors for biosynthetic processes. The citric acid cycle is the classic example, as it oxidizes acetyl-CoA to generate energy while simultaneously providing intermediates like alpha-ketoglutarate and oxaloacetate for the synthesis of amino acids, heme, and glucose via the gluconeogenesis pathway.

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13. (A) Allosteric control
Allosteric regulation involves the binding of specific effector molecules to sites other than the enzyme's active site. This binding induces a conformational change that either increases or decreases the enzyme's catalytic activity. This mechanism allows for rapid and reversible control of metabolic flux in response to the immediate needs of the cell, often targeting the rate-limiting enzyme of a pathway.

14. (C) It catalyzes the slowest, irreversible step of the pathway.
The rate-limiting enzyme catalyzes the slowest step in a metabolic pathway, effectively determining the overall speed of the process. These reactions are typically far from equilibrium and physiologically irreversible under cellular conditions. Because they serve as bottlenecks, these enzymes are the primary targets for regulatory mechanisms, such as allosteric modulation and covalent modification, to control the production of metabolic end products.

15. (D) Kinases
Kinases are a specific class of enzymes that catalyze the transfer of a phosphate group from a high-energy donor, typically ATP, to a specific substrate. In the context of covalent modification, protein kinases attach phosphate groups to serine, threonine, or tyrosine residues of target proteins. This modification often alters the protein's conformation and activity, serving as a fundamental regulatory mechanism.

16. (C) Both the substrate and an allosteric modulator
In allosteric regulation, a homotropic effector is a molecule that acts as both the substrate and a modulator for the enzyme. Typically, the binding of the substrate to one active site increases the affinity of the other subunits for the substrate, a phenomenon known as cooperativity. This results in a sigmoidal kinetic curve, allowing the enzyme to be highly sensitive.

17. (B) Activation of zymogens in the digestive system
Proteolytic cleavage is an irreversible form of post-translational modification used to activate certain enzymes. Many digestive enzymes, such

as trypsin and chymotrypsin, are synthesized as inactive precursors called zymogens. Upon reaching the appropriate physiological environment, specific peptide bonds are cleaved, allowing the protein to fold into its active conformation. This mechanism protects the site of synthesis from premature enzymatic degradation.

18. (D) It shifts the sigmoidal kinetic curve to the right.
Allosteric inhibitors decrease an enzyme's affinity for its substrate, which increases the concentration required to reach half-maximal velocity. Graphically, this is represented by a rightward shift in the sigmoidal velocity versus substrate concentration curve. This shift indicates that the enzyme is less active at a given substrate level, effectively slowing down the metabolic pathway in response to the inhibitor's presence.

19. (A) Covalent modification requires the action of secondary enzymes.
Covalent modification involves the addition or removal of chemical groups to an enzyme, a process mediated by other specific enzymes like kinases and phosphatases. In contrast, allosteric regulation depends on the non-covalent, reversible binding of effectors directly to the enzyme. While both mechanisms regulate activity, covalent modification typically provides a more sustained response and can be triggered by external hormonal signaling pathways.

20. (A) Both A and R are true and R is the correct explanation of A.
Hexokinase catalyzes the first step of glycolysis, but it is not the primary rate-limiting enzyme because its product, glucose-6-phosphate, is a branch point for several pathways. It can enter the pentose phosphate pathway or be used for glycogen synthesis. Therefore, regulating hexokinase alone does not uniquely control glycolytic flux, a role primarily reserved for phosphofructokinase-1, which follows the branch point.

21. (A) AMP
Adenosine monophosphate serves as a sensitive indicator of a cell's low energy status. When ATP is consumed rapidly, adenylate kinase produces AMP, which then acts as a potent allosteric activator for enzymes in catabolic pathways, such as phosphofructokinase-1. By sensing the rise in AMP levels, the cell can accelerate energy-generating processes to restore ATP concentrations and maintain metabolic homeostasis.

22. (D) It covalently downregulates enzyme activity.
In bacteria, glutamine synthetase is regulated by the covalent attachment of an AMP molecule to a specific tyrosine residue, a process called adenylation. This modification is catalyzed by adenylyltransferase and serves to decrease the enzyme's activity. As more subunits of the dodecameric enzyme are adenylated, its total catalytic capacity drops, allowing the cell to fine-tune glutamine production based on nitrogen availability.

23. (B) The first committed step of the pathway
Feedback inhibition is a regulatory mechanism where the end product of a biosynthetic pathway inhibits an enzyme earlier in the sequence. By targeting the first committed step, the cell avoids the unnecessary synthesis of intermediates once the final product is sufficiently abundant. This ensures metabolic efficiency and prevents the wasteful consumption of energy and precursors when the pathway's output is not required.

24. (C) Prenylation
Prenylation is a type of covalent modification involving the addition of hydrophobic isoprenoid lipids, such as farnesyl or geranylgeranyl groups, to specific cysteine residues near the C-terminus of a protein. This lipid anchor facilitates the association of soluble proteins with cellular membranes. This modification is critical for the proper localization and function of signaling proteins, including members of the Ras superfamily.

25. (D) Phosphofructokinase-1
Phosphofructokinase-1 catalyzes the phosphorylation of fructose-6-phosphate to fructose-1,6-bisphosphate using one molecule of ATP. This reaction is the primary committed step in glycolysis because the product is uniquely dedicated to the glycolytic pathway. The enzyme is highly regulated by various allosteric effectors, including ATP, AMP, and fructose-2,6-bisphosphate, ensuring that glycolytic flux matches the energy requirements of the living cell.

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26. (B) 2 ATP
During the conversion of one glucose molecule to two pyruvate molecules, two ATP are consumed in the preparatory phase and four ATP are generated via substrate-level phosphorylation in the payoff phase. This results in a net gain of two ATP molecules per glucose. While aerobic glycolysis eventually leads to more ATP through oxidative phosphorylation, the direct net glycolytic yield remains two.

27. (B) Reduction to lactate
Under anaerobic conditions, such as during intense muscular activity, the availability of oxygen is insufficient to support the complete oxidation of pyruvate via the mitochondria. To allow glycolysis to continue, pyruvate is reduced to lactate by the enzyme lactate dehydrogenase. This reaction is essential because it regenerates the NAD+ required for the glyceraldehyde-3-phosphate dehydrogenase step, maintaining the cell's energy production.

28. (B) Fructose-1,6-bisphosphate
Aldolase catalyzes the reversible cleavage of the six-carbon sugar fructose-1,6-bisphosphate into two three-carbon triose phosphates: glyceraldehyde-3-phosphate and dihydroxyacetone phosphate. This step marks the transition from the energy investment phase to the energy payoff phase of glycolysis. The two triose products are isomers, and dihydroxyacetone phosphate is subsequently converted into glyceraldehyde-3-phosphate to ensure both halves of the glucose molecule are oxidized.

29. (A) Conversion of 1,3-bisphosphoglycerate to 3-phosphoglycerate
Substrate-level phosphorylation refers to the direct transfer of a high-energy phosphate group from a metabolic intermediate to ADP, forming ATP. In glycolysis, this occurs when phosphoglycerate kinase converts 1,3-bisphosphoglycerate to 3-phosphoglycerate. Because 1,3-bisphosphoglycerate has a higher phosphate transfer potential than ATP, the reaction is thermodynamically favorable. This process allows for ATP generation without the requirement of oxygen or the electron transport chain.

30. (B) P-2, Q-1, R-3, S-4
Glycolytic enzymes are regulated by specific metabolites to ensure metabolic control. Hexokinase is inhibited by its product, glucose-6-phosphate. Phosphofructokinase-1 is potently activated by fructose-2,6-bisphosphate. Pyruvate kinase is activated by fructose-1,6-bisphosphate through feed-forward stimulation. Finally, glyceraldehyde-3-phosphate dehydrogenase requires a steady supply of NAD^+ to maintain its oxidative activity. These interactions fine-tune the flux of glucose through the pathway.

31. (D) It acts as an allosteric inhibitor of the enzyme's activity.
Phosphofructokinase-1 is a key regulatory enzyme that senses the energy status of the cell. Although ATP is a substrate, high concentrations of ATP also bind to an allosteric inhibitory site on the enzyme. This binding decreases the enzyme's affinity for fructose-6-phosphate, effectively slowing down glycolysis when energy levels are sufficient. This prevents the wasteful degradation of glucose when ATP is abundant.

32. (C) To regenerate the NAD^+ required for glycolysis to continue.
In the absence of oxygen, the mitochondrial electron transport chain cannot oxidize NADH back to NAD^+. Since NAD^+ is a mandatory cofactor for the glyceraldehyde-3-phosphate dehydrogenase reaction in glycolysis, its depletion would halt all ATP production. By reducing pyruvate to lactate, the cell regenerates NAD+, allowing glycolysis to proceed and provide a continuous, albeit small, supply of energy.

33. (B) Enolase
Fluoride ions act as a potent inhibitor of the glycolytic enzyme enolase. The inhibition occurs because fluoride forms a complex with magnesium and phosphate at the enzyme's active site, preventing the dehydration of 2-phosphoglycerate to phosphoenolpyruvate. This property is utilized in blood collection tubes containing sodium fluoride to prevent the ongoing metabolism of glucose by red blood cells before clinical testing.

34. (D) Highly exergonic and physiologically irreversible
The hexokinase reaction involves the transfer of a phosphoryl group from ATP to glucose, forming glucose-6-phosphate. This reaction is highly exergonic, meaning it releases a large amount of free energy, which makes it essentially irreversible under physiological conditions within

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the cell. This irreversibility helps to trap glucose inside the cell and marks one of the three major regulatory points of glycolysis.

35. (B) The depletion of ATP causing failure of the Na+/K+ pump.
Red blood cells depend entirely on glycolysis for ATP production as they lack mitochondria. A deficiency in pyruvate kinase, the final enzyme of glycolysis, significantly reduces ATP generation. Without sufficient ATP, the Na+/K+-ATPase pumps fail, leading to an imbalance of intracellular ions and water. This causes the cells to become rigid and prone to premature destruction in the spleen, resulting in anemia.

36. (B) Glucokinase (Hexokinase IV)
Glucokinase is a specialized hexokinase isozyme found in pancreatic beta cells and the liver. It possesses a much higher K_m for glucose compared to other hexokinases, meaning it is only fully active at high glucose concentrations. This allows beta cells to sense rising blood sugar levels and trigger insulin release accordingly. Furthermore, glucokinase is not inhibited by its product, glucose-6-phosphate.

37. (D) Pyruvate dehydrogenase
The pyruvate dehydrogenase complex catalyzes the oxidative decarboxylation of pyruvate to form acetyl-CoA, carbon dioxide, and NADH. This large multienzyme complex is located in the mitochondrial matrix and serves as the bridge between glycolysis and the tricarboxylic acid cycle. Its activity is strictly regulated by covalent modification and allosteric effectors to ensure that carbon flow into the cycle meets cellular needs.

38. (A) Oxygen is required to replenish NAD^+ and FAD via the electron transport chain.
The tricarboxylic acid cycle requires a continuous supply of oxidized cofactors, NAD^+ and FAD, to accept electrons during the oxidation of acetyl-CoA. In aerobic organisms, these cofactors are regenerated when NADH and $FADH_2$ donate their electrons to oxygen through the mitochondrial electron transport chain. Without oxygen, these carriers remain reduced, causing the cycle to stall due to lack of substrates.

39. (A) Alpha-ketoglutarate
Alpha-ketoglutarate is the five-carbon intermediate of the tricarboxylic acid (TCA) cycle formed by the oxidative decarboxylation of isocitrate. It is subsequently converted into the four-carbon compound succinyl-CoA by the alpha-ketoglutarate dehydrogenase complex, producing NADH and releasing carbon dioxide. In contrast, citrate contains six carbons, whereas succinate and malate are both four-carbon intermediates of the TCA cycle.

40. (B) I, II, III and IV
All the statements regarding the TCA cycle are correct. Succinate dehydrogenase is uniquely bound to the inner mitochondrial membrane as part of Complex II. Isocitrate dehydrogenase performs an oxidative decarboxylation step. The cycle generates exactly one FADH2 and three NADH per turn. Finally, citrate synthase, the entry enzyme, is allosterically inhibited by high levels of ATP, signaling sufficient energy.

41. (D) Conversion of succinyl-CoA to succinate
Substrate-level phosphorylation in the TCA cycle occurs during the conversion of succinyl-CoA to succinate, catalyzed by succinyl-CoA synthetase. The high-energy thioester bond of succinyl-CoA is cleaved, and the released energy is used to drive the phosphorylation of GDP to GTP (or ADP to ATP, depending on the tissue). This represents the only step in the cycle that directly produces a high-energy phosphate.

42. (C) Three
In one complete turn of the TCA cycle, three molecules of NADH are produced. These are generated by the oxidative decarboxylation of isocitrate to alpha-ketoglutarate, the oxidative decarboxylation of alpha-ketoglutarate to succinyl-CoA, and the oxidation of malate to oxaloacetate. These NADH molecules then travel to the electron transport chain to donate electrons for the production of significant amounts of ATP.

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43. (B) Anaplerotic reactions
Anaplerotic reactions are "filling up" reactions that replenish the intermediates of the tricarboxylic acid cycle. Because the cycle is amphibolic, its intermediates are frequently diverted for the biosynthesis of amino acids, heme, and glucose. To maintain the cycle's ability to oxidize acetyl-CoA for energy, these diverted intermediates must be replaced through specific pathways, such as the carboxylation of pyruvate.

44. (B) Pyruvate carboxylase
Pyruvate carboxylase catalyzes the conversion of pyruvate to oxaloacetate, requiring biotin and ATP. This is the most critical anaplerotic reaction in the liver, as it ensures that oxaloacetate levels are sufficient for both the TCA cycle and gluconeogenesis. The enzyme is allosterically activated by acetyl-CoA, ensuring that when acetyl-CoA levels are high, more oxaloacetate is produced to facilitate its oxidation.

45. (A) It acts as a suicide substrate, leading to the inhibition of aconitase.
Fluoroacetate is a metabolic poison that enters the TCA cycle and is converted into fluorocitrate by citrate synthase. Fluorocitrate then acts as a potent inhibitor of aconitase, the enzyme responsible for converting citrate to isocitrate. This "suicide inhibition" halts the cycle, leading to a toxic buildup of citrate and a failure in cellular respiration, which can be fatal to the organism.

46. (C) By the rapid removal of oxaloacetate by citrate synthase.
The oxidation of malate to oxaloacetate is thermodynamically unfavorable under standard conditions. However, in the mitochondrial matrix, the next reaction in the TCA cycle—the condensation of oxaloacetate with acetyl-CoA to form citrate—is highly exergonic. This rapid consumption of oxaloacetate by citrate synthase maintains its concentration at extremely low levels, which pulls the malate dehydrogenase reaction forward according to Le Chatelier's principle.

47. (D) Alpha-ketoglutarate dehydrogenase
The alpha-ketoglutarate dehydrogenase complex is structurally and functionally very similar to the pyruvate dehydrogenase complex. Both are large multienzyme assemblies that catalyze oxidative decarboxylation, utilizing identical cofactors: thiamine pyrophosphate, lipoic acid, FAD, NAD^+, and Coenzyme A. They both produce a thioester product and reduce NAD^+ to NADH, representing key regulatory sites that control the flux of carbon through mitochondrial pathways.

48. (C) Acetyl-CoA + 3 NAD^+ + FAD + GDP + Pi $\rightarrow$ 2 CO_2 + 3 NADH + $FADH_2$ + GTP + CoA
The net equation for the TCA cycle summarizes the entry of one two-carbon acetyl group and the subsequent release of two molecules of carbon dioxide. During the cycle, three NAD^+ are reduced to NADH, one FAD is reduced to $FADH_2$, and one GDP is phosphorylated to GTP. This process captures the high-energy electrons from the acetyl group for later use in ATP synthesis.

49. (B) Cytosol
The hexose monophosphate shunt, also known as the pentose phosphate pathway, occurs entirely within the cytosol of the cell. This location is strategically important because the primary products of the pathway, NADPH and ribose-5-phosphate, are required for biosynthetic processes such as fatty acid synthesis and nucleotide production, which also take place in the cytosolic compartment of the cell.

50. (B) Glucose-6-phosphate dehydrogenase, Lactonase, 6-Phosphogluconate dehydrogenase
The oxidative phase of the HMP shunt involves three sequential steps. First, glucose-6-phosphate dehydrogenase oxidizes glucose-6-phosphate to 6-phosphogluconolactone. Second, lactonase hydrolyzes the lactone to 6-phosphogluconate. Finally, 6-phosphogluconate dehydrogenase catalyzes an oxidative decarboxylation to produce ribulose-5-phosphate. These steps are irreversible and generate two molecules of NADPH per glucose-6-phosphate molecule entered, providing the reducing power needed for various cellular biosyntheses.

51. (A) It is used for reductive biosynthesis and antioxidant defense.
The NADPH produced in the HMP shunt is a critical electron donor for reductive biosynthetic pathways, including the synthesis of fatty acids, cholesterol, and steroid hormones. Additionally, it plays a vital role in maintaining the pool of reduced glutathione. Reduced glutathione is essential for neutralizing reactive oxygen species, such as hydrogen peroxide, thereby protecting the cell from oxidative damage and maintaining integrity.

52. (C) Ribose-5-phosphate
Ribose-5-phosphate is a five-carbon sugar produced in the HMP shunt that serves as a fundamental building block for the synthesis of nucleotides and nucleic acids. It provides the sugar backbone for RNA and DNA, as well as for essential coenzymes like ATP, NAD^+, and FAD.

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In rapidly dividing cells, the demand for ribose-5-phosphate is particularly high to support genomic replication and transcription.

53. (A) Transketolases and transaldolases
The non-oxidative phase of the HMP shunt consists of a series of reversible sugar-phosphate interconversions. Transketolase transfers two-carbon units between sugars, while transaldolase transfers three-carbon units. Together, these enzymes allow the cell to redistribute carbon atoms among various pentoses, hexoses, and trioses, linking the pathway to glycolysis and providing flexibility based on the cell's specific needs for NADPH versus ribose.

54. (D) It acts as a cofactor for transketolase.
Thiamine pyrophosphate, a derivative of vitamin B1, is an essential prosthetic group for the enzyme transketolase in the HMP shunt. It facilitates the cleavage and transfer of two-carbon ketol groups between various sugar phosphates. Measuring transketolase activity in red blood cells is a common clinical method to assess a patient's thiamine status, as the enzyme's function is strictly dependent on this cofactor.

55. (B) It is channeled back into glycolysis via triose intermediates.
When a cell's demand for NADPH exceeds its requirement for ribose-5-phosphate, the excess pentose phosphates are recycled back into the glycolytic pathway. Through the actions of transketolase and transaldolase, ribose-5-phosphate is converted into fructose-6-phosphate and glyceraldehyde-3-phosphate. This ensures that the carbon atoms from the HMP shunt are utilized for energy production or other metabolic purposes rather than accumulating unnecessarily.

56. (C) Hemolytic anemia under oxidative stress
Glucose-6-phosphate dehydrogenase deficiency is a common genetic condition that impairs the production of NADPH in red blood cells. Since these cells lack other sources of NADPH, they cannot maintain sufficient levels of reduced glutathione to neutralize oxidative damage. Exposure to certain drugs, infections, or foods like fava beans causes oxidative stress, leading to the denaturation of hemoglobin and the premature destruction of erythrocytes.

57. (D) Erythrose-4-phosphate
Erythrose-4-phosphate is a four-carbon intermediate produced in the non-oxidative phase of the HMP shunt through the action of transaldolase. In many organisms, it serves as a vital precursor for the shikimate pathway, which leads to the synthesis of aromatic amino acids such as phenylalanine, tyrosine, and tryptophan. This intermediate thus provides a metabolic link between carbohydrate flux and amino acid biosynthesis.

58. (C) By the cellular NADP+/NADPH ratio controlling glucose-6-phosphate dehydrogenase
The entry of glucose-6-phosphate into the HMP shunt is primarily regulated by the enzyme glucose-6-phosphate dehydrogenase. This enzyme is highly sensitive to the concentration of its product, NADPH, which acts as a potent competitive inhibitor. When cellular levels of NADPH are high, the enzyme is inhibited, slowing the pathway. As NADPH is consumed, the inhibition is released, allowing flux to increase.

59. (B) The non-oxidative phase reverses to form ribose-5-phosphate from glycolytic intermediates.
In cells that are actively synthesizing DNA but do not require significant amounts of NADPH, the HMP shunt can bypass the oxidative phase. Instead, the cell utilizes glycolytic intermediates, fructose-6-phosphate and glyceraldehyde-3-phosphate, to synthesize ribose-5-phosphate through the reversible reactions of the non-oxidative phase. This metabolic flexibility ensures that the supply of nucleotides meets the demands of replication without producing unneeded reducing power.

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60. (C) I, II, III, IV and V
All the listed statements regarding the HMP shunt are biologically accurate. The pathway is a cytosolic process highly active in tissues requiring NADPH for lipid synthesis, such as the liver and adipose tissue. It operates without the direct generation or consumption of ATP. Furthermore, it utilizes transketolase for two-carbon transfers and serves as the primary source of ribose and NADPH for biosynthesis.

61. (D) Non-carbohydrate precursors
Gluconeogenesis is the metabolic pathway through which the body synthesizes glucose from non-carbohydrate sources. This process is

essential for maintaining blood glucose levels during periods of fasting or intense exercise when dietary intake and glycogen stores are insufficient. The primary precursors utilized include lactate, glycerol from fat breakdown, and glucogenic amino acids, predominantly alanine, which are converted into glucose in the liver.

62. (D) Pyruvate carboxylase and Phosphoenolpyruvate carboxykinase
The final step of glycolysis, the conversion of phosphoenolpyruvate to pyruvate by pyruvate kinase, is highly exergonic and irreversible. To bypass this, gluconeogenesis uses two enzymes. First, pyruvate carboxylase converts pyruvate to oxaloacetate in the mitochondria. Then, phosphoenolpyruvate carboxykinase converts oxaloacetate to phosphoenolpyruvate in the cytosol or mitochondria. This two-step detour requires significant energy input in the form of ATP and GTP.

63. (D) Skeletal muscle and liver
The Cori cycle represents a critical metabolic cooperation between skeletal muscle and the liver. During vigorous exercise, muscles produce lactate via anaerobic glycolysis. This lactate is released into the bloodstream and transported to the liver. In the liver, the lactate is converted back into glucose through gluconeogenesis, which can then be returned to the muscles to sustain ongoing energy production.

64. (C) To transfer lactate to the liver for conversion back to glucose.
The primary function of the Cori cycle is to prevent the accumulation of lactate in the muscle while simultaneously recycling carbon skeletons for glucose production. By shifting the metabolic burden of gluconeogenesis to the liver, the body maintains energy supply to active tissues under anaerobic conditions. This cycle ensures that lactate, a byproduct of muscle metabolism, is not wasted but reused efficiently.

65. (B) Even-chain fatty acids
Mammals lack the metabolic pathways to achieve a net synthesis of glucose from even-chain fatty acids. This is because the degradation of these fatty acids yields acetyl-CoA, which cannot be converted back to pyruvate or oxaloacetate for gluconeogenesis. While the glycerol backbone of fats can be used, the two carbons of acetyl-CoA are lost as carbon dioxide in the TCA cycle.

66. (C) Endoplasmic reticulum membrane
Glucose-6-phosphatase is the final enzyme of gluconeogenesis and glycogenolysis, responsible for releasing free glucose into the blood. It is uniquely located on the luminal side of the endoplasmic reticulum membrane, primarily in the liver and kidneys. This localization requires glucose-6-phosphate to be transported into the ER lumen, where it is hydrolyzed, followed by the transport of glucose back to the cytosol.

67. (C) Six
The synthesis of one molecule of glucose from two molecules of pyruvate is an energetically expensive process. It requires the consumption of four molecules of ATP and two molecules of GTP, totaling six high-energy phosphate bonds. Specifically, ATP is used by pyruvate carboxylase and phosphoglycerate kinase, while GTP is used by phosphoenolpyruvate carboxykinase. This energy input overcomes the thermodynamic barriers of the irreversible glycolytic steps.

68. (C) Fructose-2,6-bisphosphate
Fructose-2,6-bisphosphate is the most potent allosteric regulator of both glycolysis and gluconeogenesis. It activates phosphofructokinase-1, stimulating glycolysis, while simultaneously inhibiting fructose-1,6-bisphosphatase, suppressing gluconeogenesis. Its levels are controlled by the bifunctional enzyme PFK-2/FBPase-2, which is itself regulated by hormonal signals like insulin and glucagon. This ensures that the two pathways do not operate concurrently in the same cell, preventing a futile cycle.

69. (B) Biotin
Pyruvate carboxylase, the enzyme that converts pyruvate to oxaloacetate, requires the vitamin biotin as a prosthetic group. Biotin is covalently attached to a lysine residue in the enzyme and acts as a carrier of activated carbon dioxide. The reaction involves the ATP-dependent carboxylation of biotin, followed by the transfer of the carboxyl group to pyruvate to form the four-carbon intermediate oxaloacetate.

70. (A) Both A and R are true and R is the correct explanation of A.
Acetyl-CoA serves as a crucial signal for the metabolic state of the mitochondria. During fasting, the oxidation of fatty acids increases acetyl-CoA levels, which then acts as an obligate

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allosteric activator of pyruvate carboxylase. This stimulation promotes the synthesis of oxaloacetate, providing the necessary substrate for gluconeogenesis. Simultaneously, acetyl-CoA inhibits the pyruvate dehydrogenase complex, preventing the further oxidative degradation of pyruvate.

71. (A) Glutamine
During prolonged fasting or metabolic acidosis, the kidney becomes an important site of gluconeogenesis. It primarily utilizes the amino acid glutamine as a precursor. Glutamine is deaminated to form glutamate and then alpha-ketoglutarate, which enters the TCA cycle and is subsequently converted to glucose. This process also releases ammonia, which helps the kidney buffer and excrete excess hydrogen ions in the urine.

72. (B) Conversion to malate or aspartate, then specific transport.
Oxaloacetate is produced in the mitochondrial matrix but must reach the cytosol for the subsequent steps of gluconeogenesis. Since the inner mitochondrial membrane lacks a specific transporter for oxaloacetate, it is first converted into either malate by malate dehydrogenase or aspartate by transamination. These intermediates are transported to the cytosol, where they are converted back into oxaloacetate to continue the biosynthetic pathway.

73. (B) To facilitate the net conversion of acetyl-CoA to carbohydrates.
The glyoxylate cycle is a metabolic variation of the TCA cycle found in plants, bacteria, and fungi. Its primary function is to allow the net synthesis of glucose from two-carbon units like acetyl-CoA, which is derived from the breakdown of fatty acids. By bypassing the decarboxylation steps of the TCA cycle, these organisms can convert lipid stores into structural and energy-providing carbohydrates.

74. (C) Isocitrate lyase and malate synthase
The glyoxylate cycle is distinguished from the standard TCA cycle by the presence of two unique enzymes: isocitrate lyase and malate synthase. Isocitrate lyase cleaves isocitrate into succinate and glyoxylate. Malate synthase then catalyzes the condensation of glyoxylate with another molecule of acetyl-CoA to form malate. These enzymes allow the cycle to avoid the loss of carbon as CO_2, enabling carbohydrate synthesis.

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75. (C) Glyoxysome
In germinating oilseeds, the glyoxylate cycle occurs within specialized peroxisomes called glyoxysomes. These organelles contain the enzymes necessary for both the beta-oxidation of stored fatty acids and the unique reactions of the glyoxylate cycle. This spatial organization allows the efficient conversion of stored lipids into the dicarboxylic acids required for gluconeogenesis, which supports the growth of the seedling before it can perform photosynthesis.

76. (A) Glyoxylate and succinate
Isocitrate lyase catalyzes the pivotal cleavage reaction of the glyoxylate cycle. It breaks down the six-carbon intermediate isocitrate into the four-carbon compound succinate and the two-carbon compound glyoxylate. While succinate can eventually be used for gluconeogenesis after conversion to oxaloacetate, glyoxylate remains in the cycle to react with acetyl-CoA, ensuring the continuous regeneration of the pathway's intermediates without carbon loss.

77. (B) They lack isocitrate lyase and malate synthase.
Mammals are unable to convert even-chain fatty acids into glucose because they lack the two essential enzymes of the glyoxylate cycle: isocitrate lyase and malate synthase. Although mammals can produce acetyl-CoA from fat, the TCA cycle decarboxylates these carbons, preventing any net gain of oxaloacetate. Consequently, they cannot achieve the net synthesis of glucose from the two-carbon units provided by typical lipid oxidation.

78. (B) It is transported to the mitochondria to enter the TCA cycle.
In the glyoxylate cycle, the succinate produced by the cleavage of isocitrate is not further processed within the glyoxysome. Instead, it is exported to the mitochondria, where it enters the standard TCA cycle. In the mitochondria, succinate is oxidized to malate and eventually oxaloacetate. This oxaloacetate can then be diverted into the gluconeogenesis pathway in the cytosol to produce glucose for the organism.

79. (D) Acetyl-CoA
Malate synthase is the second unique enzyme of the glyoxylate cycle. It catalyzes the condensation reaction between glyoxylate, a two-carbon intermediate, and a molecule of acetyl-CoA. This reaction produces the four-carbon dicarboxylic acid malate while releasing Coenzyme A. By utilizing a second molecule of acetyl-CoA in this manner, the cycle achieves the net synthesis of a four-carbon intermediate from two two-carbon precursors.

80. (B) P-2, Q-1, R-4, S-3
The tricarboxylic acid cycle involves oxidative decarboxylation, whereas the glyoxylate cycle enables the net synthesis of carbohydrates from acetyl-CoA by bypassing those steps. The Cori cycle facilitates the transport of lactate from muscles to the liver for glucose regeneration. Gluconeogenesis is the pathway for glucose synthesis from non-carbohydrate precursors, typically requiring biotin for the initial carboxylation of pyruvate to oxaloacetate in the mitochondria.

81. (B) By skipping the oxidative decarboxylation steps of the TCA cycle.
The glyoxylate cycle bypasses the two decarboxylation steps of the TCA cycle—catalyzed by isocitrate dehydrogenase and alpha-ketoglutarate dehydrogenase—where carbon is lost as CO_2. By cleaving isocitrate directly into succinate and glyoxylate, the cycle preserves all carbon atoms. This allows for the net accumulation of four-carbon intermediates from acetyl-CoA, which are essential for the subsequent synthesis of glucose and other cellular components.

82. (C) Growth on acetate or fatty acids as the sole carbon source
Microorganisms like Escherichia coli induce the expression of glyoxylate cycle enzymes when they must rely on two-carbon compounds, such as acetate, or fatty acids as their primary carbon and energy source. Under these conditions, the standard TCA cycle would deplete intermediates for biosynthesis without replenishing them. The glyoxylate cycle provides a metabolic solution by allowing the net synthesis of the four-carbon units required for growth.

83. (D) Malate
In the coordinated metabolic effort to synthesize glucose in plants, malate serves as the key intermediate. Malate produced within the glyoxysome or via the TCA cycle in the mitochondria is transported into the cytosol. Once in the cytosol, it is oxidized to oxaloacetate, which then serves as the starting substrate for the gluconeogenesis pathway. This shuttle mechanism effectively bridges the different organelles involved in carbohydrate synthesis.

84. (D) One molecule of succinate
For every two molecules of acetyl-CoA that enter the glyoxylate cycle, the net result is the production of one molecule of succinate. The cycle uses one acetyl-CoA to form citrate and another to react with glyoxylate to form malate. After completing the cycle's unique steps, the extra four carbons emerge as succinate, which can then be used for biosynthetic purposes, such as the synthesis of glucose.

85. (C) NADH-Q oxidoreductase
Complex I of the mitochondrial electron transport chain is formally known as NADH-Q oxidoreductase or NADH dehydrogenase. It is a large, L-shaped multienzyme complex that catalyzes the transfer of two electrons from NADH to ubiquinone. This electron transfer is coupled with the pumping of four protons from the mitochondrial matrix into the intermembrane space, contributing to the establishment of the electrochemical proton gradient.

86. (B) Ubiquinone (Coenzyme Q)
Ubiquinone, also known as Coenzyme Q, is a small, lipophilic molecule that resides and operates within the hydrophobic core of the inner mitochondrial membrane. It acts as a mobile electron carrier, accepting electrons from both Complex I and Complex II and delivering them to Complex III. Because of its lipid solubility, ubiquinone can move freely between these membrane-bound complexes to facilitate the continuous flow of electrons.

87. (A) From carriers with more negative to more positive potential.
Electron flow through the mitochondrial transport chain is thermodynamically driven by the difference in standard reduction potentials. Electrons move spontaneously from molecules with a low (more negative) reduction potential,

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such as NADH, to those with a higher (more positive) reduction potential, such as oxygen. Each successive carrier in the chain has a greater affinity for electrons than the previous one, ensuring a directional and efficient process.

88. (D) Complex II
Complex II, or succinate dehydrogenase, is the only component of the mitochondrial electron transport chain that does not pump protons across the inner membrane. While it successfully transfers electrons from succinate to ubiquinone via $FADH_2$, the free energy change associated with this specific reaction is insufficient to drive the transport of protons. Consequently, the oxidation of $FADH_2$ contributes less to the overall proton-motive force.

89. (C) 10
The transfer of a pair of electrons from NADH to the terminal acceptor, oxygen, results in the pumping of ten protons across the inner mitochondrial membrane. Specifically, four protons are pumped by Complex I, four by Complex III via the Q cycle, and two by Complex IV. This accumulation of protons in the intermembrane space creates the electrochemical gradient used by ATP synthase to produce energy.

90. (A) III → II → I → IV
Electrons from NADH enter the chain at Complex I and are then transferred to ubiquinone. Ubiquinone carries the electrons to Complex III, which in turn passes them to the mobile protein cytochrome c. Finally, cytochrome c delivers the electrons to Complex IV, where they are used to reduce molecular oxygen to water. This precise sequence ensures the gradual release of energy for proton pumping.

91. (C) Oxygen
Molecular oxygen serves as the terminal electron acceptor in the aerobic mitochondrial electron transport chain. At Complex IV, oxygen accepts four electrons and four protons from the matrix to form two molecules of water. This consumption of oxygen is the primary reason for aerobic respiration; without it, the entire electron transport chain would become backed up, halting both electron flow and ATP synthesis in the cell.

92. (D) Complex IV
Cyanide is a lethal poison that binds with high affinity to the ferric iron in the heme a3-CuB center of cytochrome c oxidase, also known as Complex IV. This binding prevents the transfer of electrons to oxygen, effectively stopping the entire electron transport chain. As a result, the proton gradient collapses and ATP production ceases, leading to rapid cellular and systemic death due to metabolic failure.

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93. (A) One
Cytochrome c is a small, water-soluble peripheral membrane protein that functions as a single-electron carrier. It contains a heme group that cycles between the ferrous and ferric states as it accepts one electron from Complex III and subsequently delivers it to Complex IV. Because oxygen reduction at Complex IV requires four electrons, four molecules of cytochrome c must sequentially deliver their electrons to complete the reduction.

94. (B) It facilitates electron transfer between carriers of different valency.
The Q cycle is a specialized mechanism operating in Complex III that allows the two-electron carrier ubiquinone to transfer electrons to the one-electron carrier cytochrome c. By recycling electrons through different pathways within the complex, the Q cycle also facilitates the pumping of four protons into the intermembrane space for every pair of electrons processed. This ensures the efficient conversion of electron flow into a proton gradient.

95. (A) Cytochrome a3 and Copper B center
Complex IV contains a specialized catalytic site consisting of a heme a3 iron atom and a copper ion known as the CuB center. Together, they form a binuclear center that tightly binds molecular oxygen. This arrangement ensures that oxygen is fully reduced to water without the premature release of partially reduced, highly reactive oxygen species like superoxide or peroxide, which could cause significant cellular damage.

96. (D) Between Complex I and Ubiquinone
Amytal, a barbiturate, and rotenone, a natural insecticide, are classical inhibitors of cellular respiration. They specifically block the transfer of electrons from the iron-sulfur clusters of Complex I to ubiquinone. By inhibiting this first

step of the electron transport chain for NADH-derived electrons, these substances prevent the formation of the proton gradient and significantly reduce the cell's ability to generate ATP.

97. (A) A proton-motive force across the inner mitochondrial membrane.
The chemiosmotic theory states that the energy released by the electron transport chain is used to pump protons from the matrix to the intermembrane space. This creates a proton-motive force, consisting of both a pH gradient and an electrical potential. ATP synthase then utilizes the spontaneous flow of protons back into the matrix to provide the mechanical energy necessary for the synthesis of ATP.

98. (A) A chemical gradient (delta-pH) and an electrical gradient (delta-psi)
The proton-motive force represents the total potential energy stored in the electrochemical gradient of protons across the inner mitochondrial membrane. It has two distinct components: the chemical gradient, which arises from the difference in proton concentration (pH), and the electrical gradient, which results from the separation of charge across the membrane. Both components contribute to the driving force that powers the synthesis of ATP.

99. (D) F0-c ring
The F0 domain of ATP synthase is embedded within the inner mitochondrial membrane and contains the proton-conducting channel. Specifically, the c ring is a rotating assembly of subunits that carries protons from the intermembrane space to the matrix. The movement of protons through this ring generates the rotational torque that is transmitted to the F1 domain, where the catalytic synthesis of ATP actually occurs.

100. (A) I and II
ATP synthase operates through a binding change mechanism where the catalytic sites are located on the beta subunits. The central gamma subunit rotates within the alpha-beta hexamer, driven by proton flow through the F0 domain. This rotation causes the beta subunits to change their conformation, cycling through states that bind ADP, synthesize ATP, and release the product. Protons do not flow through F1.

101. (B) Open, Loose, Tight
The catalytic beta subunits of ATP synthase exist in three distinct conformational states. The 'Open' state has very low affinity for nucleotides and is where ATP is released. The 'Loose' state binds ADP and inorganic phosphate loosely. The 'Tight' state binds the substrates so tightly that they spontaneously form ATP. The rotation of the gamma subunit forces each beta subunit to cycle sequentially through these three states.

102. (C) It blocks the proton channel of the F0 subunit of ATP synthase.
Oligomycin is an antibiotic that inhibits oxidative phosphorylation by binding to the F0 domain of ATP synthase. This binding physically blocks the flow of protons through the c-ring channel, preventing the rotation required for ATP synthesis. Because electron transport and ATP synthesis are tightly coupled, the inhibition of the proton channel also causes the electron transport chain to stall due to the excessive buildup of the proton gradient.

103. (B) They allow protons to bypass ATP synthase, decoupling oxygen use from ATP.
Uncoupling agents like 2,4-dinitrophenol are lipophilic weak acids that can carry protons across the inner mitochondrial membrane, bypassing the ATP synthase channel. This dissipates the proton-motive force, allowing electron transport and oxygen consumption to proceed at maximal rates without the production of ATP. The energy that would have been used for ATP synthesis is instead released as heat, which can be physiologically dangerous.

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104. (B) To generate heat for non-shivering thermogenesis
Thermogenin, or uncoupling protein 1, is a specialized protein found in the mitochondria of brown adipose tissue. It functions as a natural uncoupler by providing an alternative pathway for protons to return to the matrix. By dissipating the proton gradient without synthesizing ATP, the energy is released as heat. This process is vital for non-shivering thermogenesis in newborns and hibernating mammals to maintain body temperature.

105. (B) 2.5
The P/O ratio represents the number of ATP molecules synthesized per pair of electrons transferred to oxygen. For NADH, the transfer of

two electrons leads to the pumping of ten protons. Since current models suggest that roughly four protons are required for the synthesis and export of one ATP molecule, the resulting P/O ratio is approximately 2.5. This reflects the high efficiency of the mitochondrial energy conversion process.

106. (D) Electrons from $FADH_2$ bypass Complex I, resulting in fewer protons pumped.
Electrons from $FADH_2$ enter the electron transport chain at Complex II rather than Complex I. Because Complex I is a major site of proton pumping, its bypass means that only six protons are pumped per pair of electrons from $FADH_2$, compared to ten for NADH. Consequently, the oxidation of $FADH_2$ generates less of a proton-motive force and yields a lower P/O ratio of approximately 1.5.

107. (A) Adenine nucleotide translocase
Adenine nucleotide translocase is an antiporter located in the inner mitochondrial membrane that essential for energy exchange. It couples the export of one ATP molecule from the matrix to the cytosol with the import of one ADP molecule into the matrix. This process is driven by the membrane potential, as the exchange of ATP (-4 charge) for ADP (-3 charge) is electrogenically favorable in the energized mitochondria.

108. (C) It increases to compensate for lower mitochondrial ATP production.
When an uncoupler dissipates the proton gradient, mitochondrial ATP synthesis stops, leading to a rapid drop in cellular energy levels. To compensate for this loss, the cell significantly increases the rate of glycolysis to generate ATP via substrate-level phosphorylation. This phenomenon, known as the Pasteur effect, is a survival mechanism intended to maintain essential cellular functions despite the failure of oxidative phosphorylation.

109. (A) Mitochondrial matrix
Beta-oxidation is the primary pathway for the degradation of fatty acids and occurs within the mitochondrial matrix of mammalian cells. This location is advantageous because the products of the pathway—acetyl-CoA, NADH, and $FADH_2$—can immediately enter the citric acid cycle and the electron transport chain, which are also located in the mitochondria. This proximity ensures the efficient conversion of stored lipids into cellular energy.

110. (A) Both A and R are true and R is the correct explanation of A.
The inner mitochondrial membrane is impermeable to long-chain fatty acids and their CoA derivatives. To enter the matrix for beta-oxidation, these fatty acids must be converted to fatty acyl-carnitine by carnitine palmitoyltransferase I. They are then transported across the membrane by a specific translocase and converted back into acyl-CoA by carnitine palmitoyltransferase II. This carnitine shuttle represents a major regulatory checkpoint for fat oxidation.

111. (B) Fatty acyl-CoA
Before fatty acids can be metabolized, they must be activated in the cytosol by the enzyme acyl-CoA synthetase. This reaction uses the energy from ATP hydrolysis to attach the fatty acid to Coenzyme A, forming a high-energy fatty acyl-CoA thioester. The activation process involves an intermediate fatty acyl-AMP and is essentially irreversible due to the subsequent hydrolysis of pyrophosphate, ensuring that the fatty acid is committed to metabolism.

112. (B) Oxidation, Hydration, Oxidation, Cleavage (Thiolysis)
The beta-oxidation pathway follows a recurring cycle of four chemical reactions. First, the acyl-CoA is oxidized to form a double bond. Second, the double bond is hydrated to add a hydroxyl group. Third, the hydroxyl group is oxidized to a ketone. Finally, the bond between the alpha and beta carbons is cleaved by a thiolase enzyme, releasing one molecule of acetyl-CoA and a shorter fatty acid.

113. (A) Two
Each round of the beta-oxidation cycle results in the removal of a two-carbon fragment from the carboxyl end of the fatty acyl chain. This fragment is released as one molecule of acetyl-CoA. The remaining fatty acid, now two carbons shorter, re-enters the cycle to repeat the process until the entire chain is completely degraded into acetyl-CoA units. This sequential shortening allows for the efficient breakdown of long lipid molecules.

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114. (B) 8
Palmitic acid, a 16-carbon saturated fatty acid, undergoes seven rounds of beta-oxidation. Each of the first six rounds releases one molecule of acetyl-CoA and shortens the chain by two carbons. The final seventh round cleaves the remaining four-carbon butyryl-CoA into two molecules of acetyl-CoA. Therefore, the complete degradation of one palmitate molecule yields a total of eight molecules of acetyl-CoA.

115. (B) Propionyl-CoA
The beta-oxidation of odd-chain fatty acids proceeds identically to that of even-chain acids until the final round. In the last step, a five-carbon fatty acyl-CoA is cleaved into one molecule of acetyl-CoA (two carbons) and one molecule of propionyl-CoA (three carbons). Unlike acetyl-CoA, propionyl-CoA must undergo a specialized three-step pathway to enter the citric acid cycle as succinyl-CoA, allowing the cell to utilize the entire carbon skeleton.

116. (D) Succinyl-CoA
Propionyl-CoA, the three-carbon product of odd-chain fatty acid oxidation, is converted into succinyl-CoA through a series of three enzymatic reactions. This pathway requires the vitamins biotin and B12. Succinyl-CoA then enters the citric acid cycle as a four-carbon intermediate. Because succinyl-CoA can be used for the net synthesis of oxaloacetate, odd-chain fatty acids, unlike even-chain acids, can technically serve as a source for gluconeogenesis.

117. (A) Enoyl-CoA isomerase
Monounsaturated fatty acids contain a cis-double bond that is not a suitable substrate for the standard enzymes of beta-oxidation. When the cycle reaches this bond, the enzyme enoyl-CoA isomerase is required to shift the position and change the configuration from cis to trans. This isomerization creates a trans-delta-2-enoyl-CoA intermediate, which is a normal substrate for the rest of the beta-oxidation pathway to proceed.

118. (B) 2,4-Dienoyl-CoA reductase
The oxidation of polyunsaturated fatty acids is more complex than that of saturated fats due to multiple double bonds. In addition to enoyl-CoA isomerase, these fatty acids require 2,4-dienoyl-CoA reductase. This enzyme uses NADPH to reduce a pair of double bonds into a single trans-double bond. This conversion is necessary to remove the steric and electronic barriers that would otherwise halt the beta-oxidation cycle for these specific lipid structures.

119. (B) Peroxisomes
Very long-chain fatty acids, containing 22 or more carbons, are too large to be efficiently handled by mitochondrial enzymes. Instead, they are initially transported to peroxisomes, where they undergo a modified version of beta-oxidation. Once these chains are shortened to a more manageable length, typically eight carbons, they are transferred to the mitochondria for complete oxidation. This peroxisomal processing is essential for preventing the toxic accumulation of these lipids.

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120. (B) P-3, Q-4, R-1, S-2
The enzymes of beta-oxidation work sequentially to degrade fatty acids. Acyl-CoA dehydrogenase performs the first oxidation, generating $FADH_2$. Enoyl-CoA hydratase then adds water across the resulting double bond. Beta-hydroxyacyl-CoA dehydrogenase performs the second oxidation, producing NADH. Finally, thiolase cleaves the chain to release acetyl-CoA. This matched set of reactions efficiently extracts high-energy electrons and carbon units from the fatty acid chain for cellular use.

121. (A) Cytosol
De novo fatty acid biosynthesis primarily occurs in the cytosol of eukaryotic cells, particularly in the liver, lactating mammary glands, and adipose tissue. This spatial separation from the mitochondrial beta-oxidation pathway allows the cell to independently regulate these opposing processes. The cytosol provides the necessary environment, including high levels of NADPH, required for the reductive assembly of long-chain fatty acids from two-carbon units.

122. (A) Acetyl-CoA carboxylase
Acetyl-CoA carboxylase catalyzes the irreversible carboxylation of acetyl-CoA to form malonyl-CoA. This reaction is the committed and rate-limiting step of fatty acid synthesis. Malonyl-CoA serves as the activated donor of two-carbon units for the growing acyl chain. Because of its pivotal role, this enzyme is subject to intensive regulation by allosteric effectors, such as citrate and palmitoyl-CoA, and by hormonal signaling via phosphorylation.

123. (C) Biotin
The conversion of acetyl-CoA to malonyl-CoA by acetyl-CoA carboxylase requires the vitamin cofactor biotin. Biotin is covalently bound to the enzyme and serves as a carrier for the carboxyl group derived from bicarbonate. The reaction is ATP-dependent, where the energy is used to activate the CO_2 on the biotin molecule before it is transferred to the acetyl-CoA substrate, forming the three-carbon malonyl intermediate.

124. (B) As citrate via the citrate transport system
Acetyl-CoA is produced in the mitochondrial matrix but cannot cross the inner membrane to the cytosol where fatty acid synthesis occurs. To solve this, it condenses with oxaloacetate to form citrate, which is then transported out via a specific carrier. In the cytosol, citrate is cleaved by ATP-citrate lyase back into oxaloacetate and acetyl-CoA. This shuttle also helps transfer reducing power in the form of NADPH.

125. (D) A single multifunctional polypeptide functioning as a homodimer
In mammals, fatty acid synthase is a complex multienzyme system consisting of a single, large multifunctional polypeptide chain. This polypeptide contains seven distinct catalytic activities and an acyl carrier protein domain. The functional enzyme exists as a homodimer, where the two subunits work in concert to synthesize two fatty acid chains simultaneously. This integrated structure increases the efficiency of the synthesis by keeping the intermediates protein-bound throughout the process.

126. (A) NADPH
NADPH serves as the essential reducing agent for the two reductive steps in each cycle of fatty acid biosynthesis. These steps involve the reduction of a keto group to a hydroxyl group and the subsequent reduction of a double bond to a single bond. The required NADPH is primarily supplied by the pentose phosphate pathway and the activity of the malic enzyme, linking carbohydrate metabolism to lipid storage.

127. (B) Acyl carrier protein (ACP)
During the synthesis of fatty acids, the growing acyl intermediates are covalently linked to the acyl carrier protein (ACP) component of the fatty acid synthase complex. ACP contains a phosphopantetheine prosthetic group that acts as a flexible "swinging arm," moving the substrate from one active site to another within the multienzyme complex. This mechanism ensures that the intermediates remain sequestered and are efficiently processed through the repeating rounds of elongation.

128. (B) Palmitic acid (16:0)
The mammalian fatty acid synthase complex terminates synthesis after seven rounds of elongation, resulting in the production of the 16-carbon saturated fatty acid, palmitate. Once the chain reaches this length, it is released from the complex by a thioesterase activity. Palmitate then serves as the primary precursor for the synthesis of longer fatty acids and various unsaturated fats through subsequent elongation and desaturation reactions in different organelles.

129. (B) Endoplasmic reticulum and Mitochondria
While the de novo synthesis of palmitate occurs in the cytosol, the elongation of this 16-carbon fatty acid to form longer chains, such as stearate (18:0) or arachidate (20:0), takes place primarily in the endoplasmic reticulum and mitochondria. These organelles contain specific elongase enzymes that utilize malonyl-CoA (in the ER) or acetyl-CoA (in mitochondria) as the donor of two-carbon units to extend the fatty acid backbone.

130. (B) I, II, III and IV
All statements regarding fatty acid desaturation in mammals are correct. Desaturation occurs in the endoplasmic reticulum via a mixed-function oxidase system involving cytochrome b5 and molecular oxygen. Mammals can only introduce double bonds up to the C-9 position; they lack the enzymes to desaturate further towards the methyl end. Consequently, omega-3 and omega-6 fatty acids, like linoleic acid, are considered essential nutrients.

131. (B) Citrate
Citrate acts as the primary allosteric activator of acetyl-CoA carboxylase, the rate-limiting enzyme of fatty acid synthesis. High levels of cytosolic citrate signal that both energy and carbon precursors are abundant in the mitochondria and available for export. Citrate binding induces the polymerization of inactive enzyme dimers into active long filaments, significantly increasing the rate of malonyl-CoA production and committing the cell to lipid biosynthesis.

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132. (B) It inactivates the enzyme, stopping fatty acid synthesis.
AMP-activated protein kinase (AMPK) acts as a cellular energy sensor that is activated when ATP levels are low (and AMP levels are high). When active, AMPK phosphorylates acetyl-CoA carboxylase, causing it to dissociate into inactive dimers. This inhibition halts the energy-consuming process of fatty acid synthesis, preserving resources until the cell's energy status is restored, thus integrating lipid metabolism with overall cellular bioenergetics.

133. (B) Liver
Ketone bodies are primarily synthesized in the mitochondria of hepatocytes within the liver. Although the liver produces these energy-rich molecules, it cannot utilize them for its own energy needs. Instead, the liver exports acetoacetate and beta-hydroxybutyrate into the bloodstream to serve as alternative fuels for extrahepatic tissues, such as the heart, skeletal muscle, and brain, especially during periods of low carbohydrate availability.

134. (B) Acetyl-CoA
The three chemical species referred to as ketone bodies are acetoacetate, beta-hydroxybutyrate, and acetone. Acetyl-CoA is the common metabolic intermediate used as the starting material for their synthesis, but it is not classified as a ketone body itself. Acetoacetate and beta-hydroxybutyrate are functional fuels, whereas acetone is a spontaneous breakdown product of acetoacetate that is primarily excreted through the lungs and skin.

135. (B) HMG-CoA synthase
HMG-CoA synthase is the enzyme that catalyzes the rate-limiting step in ketogenesis. It facilitates the condensation of acetoacetyl-CoA with a third molecule of acetyl-CoA to form 3-hydroxy-3-methylglutaryl-CoA (HMG-CoA). This mitochondrial version of the enzyme is distinct from the cytosolic isoform used in cholesterol synthesis. Its regulation ensure that ketone body production is strictly controlled in response to the metabolic state of the organism.

136. (B) Prolonged fasting or uncontrolled diabetes mellitus states.
Ketogenesis is strongly promoted under conditions where there is a high rate of fatty acid oxidation combined with low carbohydrate availability, such as during prolonged fasting or uncontrolled diabetes. In these states, oxaloacetate is diverted to gluconeogenesis, causing acetyl-CoA to accumulate in the liver mitochondria. This excess acetyl-CoA is then shunted into the ketogenic pathway to produce alternative fuels for the body's peripheral tissues.

137. (A) Acetoacetate and Acetyl-CoA
During the final steps of ketogenesis, the enzyme HMG-CoA lyase cleaves 3-hydroxy-3-methylglutaryl-CoA (HMG-CoA) into one molecule of acetoacetate and one molecule of acetyl-CoA. Acetoacetate is the first functional ketone body produced. It can either be released into the blood as is, reduced to beta-hydroxybutyrate by a dehydrogenase, or spontaneously decarboxylate to form acetone. This cleavage reaction is essential for the net production of ketone fuels.

138. (C) It lacks the enzyme thiophorase (beta-ketoacyl-CoA transferase).
The liver is unable to utilize ketone bodies for energy because it lacks the enzyme thiophorase, also known as beta-ketoacyl-CoA transferase. This enzyme is required in extrahepatic tissues to transfer a Coenzyme A group from succinyl-CoA to acetoacetate, activating it for subsequent cleavage and entry into the citric acid cycle. By lacking this enzyme, the liver ensures that the ketone bodies it synthesizes are reserved for export.

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139. (B) By converting them to acetyl-CoA for entry into the TCA cycle.
Extrahepatic tissues utilize ketone bodies by converting them back into acetyl-CoA units. In the mitochondria of these tissues, beta-hydroxybutyrate is first oxidized to acetoacetate, which is then activated by thiophorase using succinyl-CoA. The resulting acetoacetyl-CoA is cleaved by thiolase into two molecules of acetyl-CoA. These acetyl-CoA molecules then enter the citric acid cycle to be oxidized for ATP production, providing a vital energy source.

140. (B) beta-hydroxybutyrate dehydrogenase, Thiophorase, Thiolase
The utilization of beta-hydroxybutyrate in peripheral tissues follows a specific three-step sequence. First, beta-hydroxybutyrate dehydrogenase oxidizes it to acetoacetate, producing NADH. Second, thiophorase transfers

a CoA group from succinyl-CoA to form acetoacetyl-CoA. Third, thiolase cleaves the acetoacetyl-CoA into two molecules of acetyl-CoA. This sequence allows the energy stored in ketone bodies to be efficiently extracted and integrated into the central metabolic pathways for ATP generation.

141. (B) Acetone
The "fruity" or "sweet" breath odor associated with diabetic ketoacidosis is caused by the production of acetone. When acetoacetate levels are extremely high in the blood, a small portion undergoes spontaneous, non-enzymatic decarboxylation to form acetone. Because acetone is highly volatile, it is easily excreted through the lungs during respiration. This symptom is a clinical hallmark of severe metabolic imbalance and excessive ketone body accumulation in the system.

142. (A) Depletion of oxaloacetate used for gluconeogenesis.
During starvation, the liver aggressively synthesizes glucose via gluconeogenesis, which depletes the mitochondrial pool of oxaloacetate. Since oxaloacetate is the necessary partner for acetyl-CoA to enter the TCA cycle, its absence prevents acetyl-CoA oxidation. The resulting accumulation of acetyl-CoA, driven by high rates of fatty acid breakdown, triggers the ketogenic pathway. This diversion ensures that fatty acid energy is converted into transportable ketone fuels for the brain.

143. (C) Ketone bodies are water-soluble and travel freely in the plasma.
Unlike free fatty acids, which are highly hydrophobic and must be carried by serum albumin, ketone bodies are water-soluble organic molecules. They can dissolve directly in the blood plasma and travel freely to various tissues without the need for specialized transport proteins or lipoproteins. This solubility allows for rapid distribution and uptake by extrahepatic tissues, making ketone bodies a highly efficient and mobile energy source.

144. (C) They are organic acids that dissociate at physiological pH.
Acetoacetate and beta-hydroxybutyrate are organic carboxylic acids with pK_a values well below physiological pH. Consequently, they dissociate and release a proton when they enter the bloodstream. In conditions like uncontrolled diabetes, their massive overproduction exceeds the blood's buffering capacity, leading to a significant decrease in systemic pH. This condition, known as ketoacidosis, is a medical emergency that can disrupt normal cellular and organ function.

145. (A) Glycerol-3-phosphate
The synthesis of triglycerides begins with the glycerol-3-phosphate backbone, which can be derived from the phosphorylation of glycerol or the reduction of dihydroxyacetone phosphate. Two fatty acyl-CoA molecules are sequentially attached to the C-1 and C-2 positions of the glycerol-3-phosphate by acyltransferases to form phosphatidic acid. The phosphate group is then removed, and a third fatty acid is added to the C-3 position to complete the triacylglycerol molecule.

146. (A) Phosphatidic acid
Phosphatidic acid is a central intermediate that serves as a common precursor for both triglyceride synthesis and the production of several major glycerophospholipids. In the biosynthetic pathway, it can be dephosphorylated to form diacylglycerol, which is the precursor for triglycerides and phosphatidylcholine. Alternatively, it can be activated by reacting with CTP to form CDP-diacylglycerol, which leads to the synthesis of phosphatidylinositol and cardiolipin.

147. (B) Utilization of CTP to form activated CDP-intermediates
The synthesis of complex phospholipids is an endergonic process driven by the use of cytidine triphosphate (CTP). Depending on the specific phospholipid, either the polar head group (as in phosphatidylcholine) or the diacylglycerol backbone (as in phosphatidylinositol) is activated by conjugation with cytidine monophosphate. The resulting CDP-intermediate possesses a high-energy bond, providing the thermodynamic force needed to link the two components of the final phospholipid molecule.

148. (B) Dipalmitoylphosphatidylcholine (DPPC)
Dipalmitoylphosphatidylcholine is the primary functional component of pulmonary surfactant. This unique phospholipid contains two saturated palmitoyl chains, allowing it to pack tightly at the air-water interface of the alveoli. This

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arrangement significantly reduces surface tension, preventing the collapse of the lungs during expiration and minimizing the work required for breathing. A deficiency in this lipid in premature infants leads to neonatal respiratory distress syndrome.

149. (B) Base-exchange reaction with phosphatidylethanolamine or phosphatidylcholine
In mammals, phosphatidylserine is not synthesized through a primary de novo pathway. Instead, it is produced via a base-exchange reaction where the polar head group of a pre-existing phospholipid, such as phosphatidylethanolamine or phosphatidylcholine, is replaced by a free serine molecule. This reaction occurs in the endoplasmic reticulum and is catalyzed by specific phosphatidylserine synthases, ensuring the proper distribution of serine-containing lipids in cellular membranes.

150. (A) I, II and IV
Sphingolipids are built on a sphingosine backbone synthesized from palmitoyl-CoA and serine. Attachment of a fatty acid to sphingosine via an amide bond creates ceramide. Sphingomyelin is formed by adding a phosphorylcholine group to ceramide and does not contain glycerol. Gangliosides are complex glycosphingolipids containing one or more sialic acid residues. These statements accurately describe the structural and biosynthetic characteristics of this diverse lipid class.

151. (C) Ceramide
Ceramide, consisting of a fatty acid linked to a sphingosine backbone, is the fundamental precursor for all complex sphingolipids. By adding different polar head groups to the hydroxyl group of ceramide, the cell produces various molecules. Adding phosphorylcholine yields sphingomyelin, while adding one or more sugar residues creates glycosphingolipids such as cerebrosides and gangliosides. Thus, ceramide metabolism sits at a critical junction in the biosynthesis of membrane structural components.

152. (A) Two molecules of phosphatidic acid connected by a glycerol bridge
Cardiolipin, or diphosphatidylglycerol, has a unique structure consisting of four fatty acid tails and three glycerol groups. Specifically, it is composed of two molecules of phosphatidic acid joined together by a central glycerol molecule. This complex, dimeric structure allows cardiolipin to occupy a large volume in the membrane and participate in specialized functions, particularly those related to the stability and efficiency of mitochondrial energy conversion.

153. (C) Inner mitochondrial membrane
Cardiolipin is primarily found in the inner mitochondrial membrane, where it accounts for approximately 20% of the total lipid content. It is essential for the proper folding and function of several mitochondrial proteins, including the complexes of the electron transport chain and ATP synthase. Its presence is critical for maintaining the structural integrity of the cristae and ensuring efficient oxidative phosphorylation, highlighting its importance in cellular energy metabolism.

154. (C) Peroxisomes
The biosynthesis of ether-linked phospholipids, including plasmalogens, begins in the peroxisomes. The first two enzymes of the pathway, dihydroxyacetone phosphate acyltransferase and alkyl-dihydroxyacetone phosphate synthase, are located exclusively in this organelle. These enzymes catalyze the attachment of a fatty alcohol to a glycerol backbone via an ether bond. Subsequent steps to complete the phospholipid occur in the endoplasmic reticulum, demonstrating an essential metabolic cooperation between these two organelles.

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155. (B) Phospholipase A2
Phospholipase A2 specifically cleaves the ester bond at the C-2 position of glycerophospholipids. In many cellular membranes, arachidonic acid is predominantly esterified at this position. The activation of Phospholipase A2 in response to various stimuli releases free arachidonic acid, which then serves as the primary precursor for the synthesis of eicosanoids, including prostaglandins, thromboxanes, and leukotrienes. This makes the enzyme a key regulator of inflammatory signaling.

156. (A) CDP-diacylglycerol
The biosynthesis of phosphatidylinositol requires the activation of the lipid backbone. Phosphatidic acid reacts with CTP to form the high-energy intermediate CDP-diacylglycerol. This activated molecule then reacts with free inositol to produce phosphatidylinositol and release CMP.

This pathway is particularly important for producing the precursor to phosphatidylinositol 4,5-bisphosphate, which serves as a vital substrate for cell signaling cascades involving phospholipase C and the generation of second messengers.

157. (B) Acetyl-CoA
All twenty-seven carbon atoms of cholesterol are derived from acetyl-CoA through a complex, multi-step biosynthetic pathway. Acetyl-CoA units are first condensed to form the six-carbon intermediate mevalonate, which is then converted into five-carbon activated isoprenes. These isoprene units are subsequently polymerized to form larger intermediates, ultimately leading to the cyclization and modification steps that produce the final four-ring sterol structure essential for membrane fluidity and hormone synthesis.

158. (C) Mevalonate
Mevalonate is the key six-carbon intermediate formed in the first major stage of cholesterol biosynthesis. It is synthesized through the condensation of three molecules of acetyl-CoA, followed by a two-step reduction catalyzed by HMG-CoA reductase. The formation of mevalonate marks a committed step in the pathway, as it is primarily dedicated to the production of isoprenoids and sterols. Its synthesis is the most tightly regulated point in the entire cholesterol pathway.

159. (B) HMG-CoA reductase
HMG-CoA reductase is the primary rate-limiting enzyme in the cholesterol biosynthetic pathway. It catalyzes the reduction of HMG-CoA to mevalonate using two molecules of NADPH. This enzyme is subject to multiple levels of regulation, including transcriptional control, proteolytic degradation, and covalent modification by phosphorylation. Because of its central role in determining the rate of cholesterol production, it is the target of several clinical interventions aimed at managing high cholesterol.

160. (A) Both A and R are true and R is the correct explanation of A.
Statins are pharmacological agents used to manage hypercholesterolemia by inhibiting the rate-limiting step of cholesterol biosynthesis. They function as structural analogs of the natural substrate, acting as competitive inhibitors of the enzyme HMG-CoA reductase. By blocking this enzyme, statins effectively reduce the endogenous production of cholesterol, which subsequently leads to the upregulation of LDL receptors and lower serum cholesterol levels in the blood.

161. (B) Isopentenyl pyrophosphate and Dimethylallyl pyrophosphate
In the second stage of cholesterol synthesis, mevalonate is converted into five-carbon activated isoprene units through a series of ATP-dependent reactions. These units are isopentenyl pyrophosphate and its isomer, dimethylallyl pyrophosphate. These molecules serve as the basic building blocks for all higher-order isoprenoids. Their synthesis represents the transition from a simple organic acid to the reactive phosphate-activated precursors necessary for the polymerization steps that follow in the pathway.

162. (B) Three
The synthesis of farnesyl pyrophosphate, a 15-carbon intermediate, requires three molecules of 5-carbon isoprene units. First, one molecule of dimethylallyl pyrophosphate condenses with one molecule of isopentenyl pyrophosphate to form the 10-carbon geranyl pyrophosphate. Then, geranyl pyrophosphate condenses with a second molecule of isopentenyl pyrophosphate to produce the final 15-carbon farnesyl chain. This sequential addition of five-carbon units is a fundamental characteristic of the entire isoprenoid biosynthetic pathway.

163. (B) Squalene
Squalene is a 30-carbon hydrocarbon formed by the head-to-head condensation of two 15-carbon farnesyl pyrophosphate molecules. This reaction is catalyzed by squalene synthase and requires NADPH as a reducing agent. The formation of squalene is significant because it is the first intermediate in the cholesterol pathway that is completely hydrophobic and lacks a phosphate group. Squalene then undergoes oxidation and cyclization to form the characteristic sterol ring system.

164. (B) Lanosterol
Lanosterol is the first intermediate in the cholesterol biosynthetic pathway that contains the characteristic four-ring steroid nucleus. It is formed from the cyclization of squalene epoxide, a process catalyzed by lanosterol cyclase. Although

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lanosterol possesses the sterol structure, it must still undergo approximately nineteen further enzymatic modifications, including the removal of three methyl groups and the migration of a double bond, to be converted into cholesterol.

165. (A) SREBPs (Sterol Regulatory Element-Binding Proteins)
Sterol Regulatory Element-Binding Proteins are the principal transcription factors that control the expression of genes involved in cholesterol and fatty acid metabolism. When cellular sterol levels are low, SREBPs are activated and translocate to the nucleus, where they bind to specific sterol regulatory elements in the promoter regions of target genes, such as HMG-CoA reductase and the LDL receptor. This binding enhances gene transcription to increase cholesterol supply.

166. (B) It promotes the exchange of bound GDP for GTP on the alpha subunit.
When intracellular cholesterol levels are high, cholesterol binds to the SCAP protein, inducing a conformational change that promotes its interaction with Insig proteins in the endoplasmic reticulum membrane. This interaction locks the SREBP-SCAP complex within the ER, preventing its transport to the Golgi for proteolytic activation. Consequently, SREBP remains inactive, and the transcription of cholesterol-producing genes is suppressed, preventing the excessive and potentially toxic accumulation of sterols.

167. (A) Ubiquinone (Coenzyme Q)
The isoprenoid pathway branch point at farnesyl pyrophosphate allows the cell to synthesize several non-sterol products in addition to cholesterol. One critical product is ubiquinone, also known as Coenzyme Q, which functions as a mobile electron carrier in the mitochondrial electron transport chain. The long hydrophobic tail of ubiquinone is composed of multiple isoprene units derived from the same pathway, illustrating how cholesterol synthesis intermediates support energy metabolism.

168. (B) Ubiquitin-proteasome pathway
HMG-CoA reductase is subject to rapid degradation when cellular sterol levels are high, a process mediated by the ubiquitin-proteasome pathway. Specific sterols and pathway intermediates induce the enzyme to interact with Insig proteins, which recruit E3 ubiquitin ligases. The enzyme is then ubiquitinated and extracted from the endoplasmic reticulum membrane for degradation by the proteasome. This post-translational regulation allows for a fast and sensitive response to sterol surplus.

169. (A) Alpha-ketoglutarate
Transamination is the first step in the catabolism of most amino acids. In this process, the alpha-amino group of an amino acid is transferred to an alpha-keto acid acceptor, which is almost always alpha-ketoglutarate. This reaction produces a new alpha-keto acid corresponding to the original amino acid and converts alpha-ketoglutarate into glutamate. This allows the cell to collect amino groups from various amino acids into a single common carrier, glutamate.

170. (A) P-3, Q-2, R-1, S-4
Transaminases catalyze the interconversion of amino acids and their corresponding alpha-keto acids. Alanine transaminase produces pyruvate, while aspartate transaminase yields oxaloacetate. Glutamate transamination typically regenerates alpha-ketoglutarate. Tyrosine transaminase converts its substrate into p-hydroxyphenylpyruvate. These reactions are essential for funneling nitrogen into the urea cycle and for providing carbon skeletons that can enter the central metabolic pathways of the cell for energy or glucose production.

171. (B) Pyridoxal phosphate (PLP)
Pyridoxal phosphate, derived from vitamin B6, is the essential cofactor for all aminotransferase enzymes. It is covalently bound to a lysine residue at the enzyme's active site. PLP acts as a temporary carrier of the amino group during the transamination reaction. It cycles between its aldehyde form, pyridoxal phosphate, and its aminated form, pyridoxamine phosphate, facilitating the transfer of the amino group from the substrate to the acceptor alpha-keto acid.

172. (B) Schiff base (aldimine)
The mechanism of transamination involves the formation of a covalent intermediate called a Schiff base, or aldimine, between the amino group of the substrate amino acid and the aldehyde group of the PLP cofactor. This intermediate stabilizes the transition state and facilitates the subsequent steps of the reaction, including the tautomerization and hydrolysis that result in the release of the alpha-keto acid product. This

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Schiff base chemistry is fundamental to many PLP-dependent enzymes.

173. (C) Glutamate dehydrogenase
Glutamate dehydrogenase is a mitochondrial enzyme that catalyzes the oxidative deamination of glutamate. It removes the amino group from glutamate as free ammonia, simultaneously reducing NAD^+ or $NADP^+$ to NADH or NADPH and regenerating alpha-ketoglutarate. This reaction is the primary way the body releases nitrogen that has been collected from various amino acids via transamination. The released ammonia is then safely processed into urea in the liver for excretion.

174. (A) It can use either NAD^+ or $NADP^+$ as an electron acceptor.
Glutamate dehydrogenase is one of the few enzymes that can utilize either NAD^+ or $NADP^+$ as a coenzyme. Typically, the NAD^+-dependent activity is involved in the oxidative deamination of glutamate for energy production, while the $NADP^+$-dependent activity is used for the reductive amination of alpha-ketoglutarate to form glutamate. This dual specificity allows the enzyme to play a central role in both the catabolism and biosynthesis of nitrogen-containing molecules.

175. (B) Serine
Serine undergoes non-oxidative deamination through the action of the enzyme serine dehydratase. Unlike most amino acids, which require transamination or oxidative deamination, serine is directly converted to pyruvate and ammonia in a reaction that involves the removal of a water molecule. This pathway provides a direct link between serine catabolism and the glycolytic intermediate pyruvate, which can then be used for energy production or gluconeogenesis in the liver.

176. (C) Pyruvate
Serine dehydratase uses pyridoxal phosphate to catalyze the conversion of serine into pyruvate and ammonia. The reaction proceeds through the dehydration of serine to form an aminoacrylate intermediate, which then spontaneously hydrolyzes to release ammonia and pyruvate. This non-oxidative pathway is an efficient way for the liver to process serine and channel its carbon atoms into the production of glucose or for oxidation in the citric acid cycle during fasting.

177. (A) As alanine and glutamine
Ammonia is a toxic byproduct of protein metabolism and must be transported to the liver in non-toxic forms. In skeletal muscle, amino groups are primarily transferred to pyruvate to form alanine via the glucose-alanine cycle. In many other tissues, ammonia is combined with glutamate to form glutamine. These two amino acids then travel safely through the bloodstream to the liver, where the ammonia is released and ultimately incorporated into urea for excretion.

178. (B) It is transaminated back to pyruvate, which is used for gluconeogenesis.
In the glucose-alanine cycle, alanine transported from the muscle arrives at the liver and undergoes transamination with alpha-ketoglutarate. This reaction regenerates pyruvate and produces glutamate. The pyruvate is then used as a primary substrate for gluconeogenesis to synthesize new glucose, which is returned to the muscle. Meanwhile, the amino group in glutamate is processed through the urea cycle to be excreted as urea, maintaining overall nitrogen balance.

179. (C) Glutamine synthetase
Glutamine synthetase catalyzes the ATP-dependent condensation of ammonia with glutamate to form glutamine. This reaction is the primary mechanism for the detoxification and transport of ammonia in most extrahepatic tissues, particularly in the brain. Glutamine is a neutral, non-toxic amino acid that can be safely transported in high concentrations through the blood to the liver and kidneys, where it serves as a donor of ammonia for urea synthesis or renal buffering.

180. (A) Branched-chain amino acids (Valine, Leucine, Isoleucine)
The branched-chain amino acids—leucine, isoleucine, and valine—are primarily catabolized in extrahepatic tissues, especially skeletal muscle. The liver lacks significant levels of the enzyme branched-chain aminotransferase required for the first step of their degradation. Muscle tissue, however, contains high levels of this enzyme, allowing it to utilize these amino acids for energy. The resulting nitrogen is then transported back

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to the liver, often as alanine, to be processed in the urea cycle.

181. (A) Partially in the liver mitochondria and partially in the cytosol
The Urea Cycle is a compartmentalized process occurring exclusively in the liver. The first two reactions—the synthesis of carbamoyl phosphate and its condensation with ornithine to form citrulline—take place within the mitochondrial matrix. Citrulline is then transported to the cytosol, where the remaining three reactions occur to complete the synthesis of urea and regenerate ornithine. This spatial separation allows for the tight regulation of ammonia entry and nitrogen processing.

182. (A) Carbamoyl phosphate synthetase I
Carbamoyl phosphate synthetase I catalyzes the initial and rate-limiting step of the Urea Cycle in the mitochondria. It combines free ammonia, bicarbonate, and two molecules of ATP to form carbamoyl phosphate. This enzyme is strictly regulated and requires N-acetylglutamate as an obligate allosteric activator. Because it controls the entry of nitrogen into the cycle, its activity is paramount for preventing the toxic accumulation of ammonia in the blood and brain.

183. (B) Two
The synthesis of one molecule of carbamoyl phosphate by carbamoyl phosphate synthetase I consumes two molecules of ATP. The first ATP is used to phosphorylate bicarbonate to form carboxyphosphate, and the second ATP phosphorylates carbamate to yield the final carbamoyl phosphate product. This high energy cost ensures the reaction is irreversible and provides the thermodynamic drive for the start of the urea cycle, facilitating the efficient removal of toxic ammonia.

184. (A) Free ammonia and aspartate
The two nitrogen atoms in a single molecule of urea originate from two different sources. The first nitrogen enters the Urea Cycle as free ammonia, which is incorporated into carbamoyl phosphate in the mitochondria. The second nitrogen is provided by the amino group of aspartate, which condenses with citrulline in the cytosol to form argininosuccinate. This dual sourcing allows the cycle to efficiently collect and excrete nitrogen from diverse metabolic origins.

185. (A) Citrulline
In the second step of the Urea Cycle, the enzyme ornithine transcarbamoylase catalyzes the transfer of the carbamoyl group from carbamoyl phosphate to the amino acid ornithine. This reaction occurs in the mitochondrial matrix and produces citrulline. Unlike ornithine, citrulline has a specific transporter that allows it to leave the mitochondria and enter the cytosol, where the subsequent nitrogen-fixing reactions of the cycle take place to form the urea molecule.

186. (A) N-acetylglutamate
N-acetylglutamate is an obligate allosteric activator of the enzyme carbamoyl phosphate synthetase I. Without its presence, the enzyme is virtually inactive, and the Urea Cycle cannot proceed. N-acetylglutamate is synthesized from acetyl-CoA and glutamate when these substrates are abundant, signaling a high rate of amino acid catabolism. This regulatory mechanism ensures that the rate of urea production is perfectly matched to the load of nitrogen that needs to be excreted.

187. (C) Fumarate
The enzyme argininosuccinate lyase cleaves the intermediate argininosuccinate into two products: arginine and fumarate. While arginine continues through the Urea Cycle to produce urea, fumarate provides a critical link to the TCA cycle. Fumarate can be converted to malate and then oxaloacetate, which can either be used for gluconeogenesis or transaminated back to aspartate to provide the next nitrogen atom for another turn of the Urea Cycle.

188. (A) Arginase
Arginase is the final enzyme of the Urea Cycle, located in the cytosol of hepatocytes. It catalyzes the hydrolytic cleavage of the arginine side chain to produce one molecule of urea and regenerate one molecule of ornithine. The urea is subsequently released into the blood for excretion by the kidneys, while the ornithine is transported back into the mitochondria to start another round of the cycle, maintaining a continuous flow of nitrogen excretion.

189. (A) The Aspartate-Argininosuccinate Shunt
The Aspartate-Argininosuccinate Shunt, often referred to as the "Krebs bicycle," links the Urea Cycle and the TCA cycle. It involves the production of fumarate in the Urea Cycle and its

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subsequent entry into the TCA cycle, as well as the transamination of oxaloacetate to aspartate for re-entry into the Urea Cycle. This integration allows for the efficient use of carbon skeletons and provides a mechanism to offset the energetic cost of urea synthesis.

190. (D) I only
The synthesis of one molecule of urea consumes a total of four high-energy phosphate bonds. Specifically, two ATP are used to form carbamoyl phosphate, and one ATP is hydrolyzed to AMP and pyrophosphate to form argininosuccinate, which counts as two bond equivalents. While the cycle is energetically expensive, the regeneration of aspartate and the processing of fumarate do not directly consume additional ATP in the primary cycle steps themselves, although they are metabolic costs.

191. (B) Argininosuccinate synthetase
A deficiency in the enzyme argininosuccinate synthetase causes Citrullinemia Type I. Because the enzyme cannot condense citrulline with aspartate, citrulline accumulates to very high levels in the blood and is excreted in the urine. Like other urea cycle defects, this condition leads to hyperammonemia, as the cycle is unable to proceed toward the final excretion of nitrogen, resulting in neurotoxicity and other severe clinical manifestations if not managed with dietary protein restriction.

192. (A) Ornithine-citrulline antiporter
The continuation of the Urea Cycle depends on the efficient transport of intermediates between the cytosol and the mitochondrial matrix. The ornithine-citrulline antiporter is a specific transport protein in the inner mitochondrial membrane that moves one molecule of citrulline out of the matrix while simultaneously moving one molecule of ornithine into the matrix. This exchange ensures that the substrate for the next cycle turn is always available where the initial reaction occurs.

193. (A) Gluconeogenesis
Glucogenic amino acids are those whose carbon skeletons can be catabolized into intermediates that serve as substrates for gluconeogenesis. These intermediates include pyruvate or any member of the tricarboxylic acid cycle, such as alpha-ketoglutarate, succinyl-CoA, fumarate, or oxaloacetate. By entering these pathways, the carbon atoms from amino acids can be successfully redirected into the net synthesis of glucose in the liver, which is crucial for maintaining blood sugar during fasting states.

194. (D) Leucine
In mammals, leucine and lysine are the only two amino acids that are exclusively ketogenic. This means their catabolism yields only acetyl-CoA or acetoacetate, neither of which can be used for the net synthesis of glucose. Instead, these carbon skeletons are either oxidized for energy in the citric acid cycle or used as precursors for the synthesis of ketone bodies and fatty acids, making them distinct from the glucogenic amino acids.

195. (B) Fumarate and Acetoacetate
Phenylalanine and tyrosine are both glucogenic and ketogenic because their complex degradation pathway yields two distinct four-carbon products. The glucogenic product is fumarate, which can enter the TCA cycle and eventually be used for glucose synthesis. The ketogenic product is acetoacetate, which can be converted to acetyl-CoA or used as a ketone body. This dual nature allows these aromatic amino acids to contribute to multiple metabolic needs depending on the cell's state.

196. (D) Oxaloacetate
The carbon skeleton of aspartate is directly linked to oxaloacetate, a central intermediate of the tricarboxylic acid cycle. Through a simple transamination reaction catalyzed by aspartate aminotransferase, the amino group of aspartate is transferred to alpha-ketoglutarate, leaving behind oxaloacetate. This conversion is highly reversible and allows aspartate to play a critical role in providing substrates for both energy production and gluconeogenesis, as well as participating in the malate-aspartate shuttle.

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197. (A) Serine
Serine is a non-essential amino acid synthesized from the glycolytic intermediate 3-phosphoglycerate. The pathway involves the oxidation of 3-phosphoglycerate to 3-phosphopyruvate, followed by transamination to form 3-phosphoserine, and finally the removal of the phosphate group to yield free serine. This direct biosynthetic route from glucose ensures that the body can maintain adequate levels of serine for protein synthesis, lipid formation,

and one-carbon metabolism without requiring dietary intake.

198. (D) Asparagine
The alpha-ketoglutarate family of amino acids includes glutamate, glutamine, proline, and arginine, all of which are catabolized to or synthesized from alpha-ketoglutarate. Asparagine, however, belongs to the oxaloacetate family. It is synthesized from and degraded to aspartate, which is then converted into oxaloacetate via transamination. These groupings help clarify how different amino acids connect to the central metabolic pathways for energy extraction or the synthesis of other biological molecules.

199. (A) Transfer of one-carbon units (e.g., methyl, methylene, formyl groups)
Tetrahydrofolate, a derivative of the vitamin folate, is the primary coenzyme responsible for the transfer of one-carbon units in various metabolic pathways. It can carry these units at different oxidation states, such as formyl, methenyl, methylene, or methyl groups. This function is essential for the synthesis of purine and pyrimidine nucleotides, the metabolism of certain amino acids like serine and glycine, and the remethylation of homocysteine to methionine.

200. (A) Both A and R are true and R is the correct explanation of A.
S-Adenosylmethionine is the most common methyl donor in biological systems. Its potency arises from the fact that the methyl group is attached to a positively charged sulfur atom, creating a sulfonium ion. This electronic arrangement makes the methyl group extremely reactive and much easier to transfer to various acceptors, such as DNA, proteins, and lipids, compared to the methyl group carried by N5-methyltetrahydrofolate, which is attached to a neutral nitrogen atom.

201. (B) Phenylalanine
Tyrosine is a non-essential amino acid only if sufficient phenylalanine, an essential amino acid, is available. The synthesis occurs through a single-step hydroxylation reaction catalyzed by the enzyme phenylalanine hydroxylase. This reaction requires molecular oxygen and the cofactor tetrahydrobiopterin. Because this is the only way to synthesize tyrosine in the body, a deficiency in phenylalanine or the hydroxylase enzyme leads to the clinical condition of phenylketonuria and a conditional requirement for tyrosine.

202. (A) Vitamin B_{12} and Folate
The remethylation of homocysteine back to methionine is a critical step in the methyl cycle that requires both Vitamin B_{12} and folate. The enzyme methionine synthase uses methylcobalamin as a cofactor to transfer a methyl group from N5-methyltetrahydrofolate to homocysteine. A deficiency in either of these vitamins can lead to elevated homocysteine levels, which is associated with an increased risk of cardiovascular disease and developmental neurological issues.

203. (A) Alanine
Alanine is the primary member of the pyruvate family of amino acids. It is synthesized from and catabolized to pyruvate through a simple, reversible transamination reaction. This close relationship allows alanine to serve as a major carrier of nitrogen and carbon from the muscles to the liver for gluconeogenesis in the glucose-alanine cycle. Other amino acids, such as serine and cysteine, are also eventually converted to pyruvate during their degradation.

204. (A) Transamination
Transamination step in the catabolism of the branched-chain amino acids leucine, isoleucine, and valine is transamination. This reaction is catalyzed by branched-chain aminotransferase and requires pyridoxal phosphate. The amino group is transferred to alpha-ketoglutarate, forming glutamate and the corresponding branched-chain alpha-keto acids. This step is followed by oxidative decarboxylation, which is a major regulatory point in the degradation of these three essential amino acids.

205. (A) Glutamate
Gamma-aminobutyric acid is the principal inhibitory neurotransmitter in the mammalian central nervous system. It is synthesized through the decarboxylation of the amino acid glutamate, a reaction catalyzed by the enzyme glutamate decarboxylase. This enzyme requires pyridoxal phosphate as a cofactor. The balance between excitatory glutamate and inhibitory GABA is crucial for normal brain function, and disruptions in this pathway are associated with various neurological disorders, including seizures and anxiety.

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206. (A) Tyrosine
The catecholamines dopamine, norepinephrine, and epinephrine are synthesized through a sequential pathway starting from the amino acid tyrosine. Tyrosine is first hydroxylated to L-DOPA, which is then decarboxylated to form dopamine. In specific cells, dopamine is further hydroxylated to norepinephrine, which can then be methylated to form epinephrine. These molecules act as critical neurotransmitters and hormones that regulate the stress response, heart rate, and various other physiological processes.

207. (D) Tryptophan
Serotonin, or 5-hydroxytryptamine, is a major neurotransmitter synthesized from the essential amino acid tryptophan. The pathway involves the hydroxylation of tryptophan to 5-hydroxytryptophan, followed by decarboxylation to produce serotonin. This process occurs in the brain and the gastrointestinal tract. Serotonin plays a central role in regulating mood, sleep, and appetite, and its metabolism is a primary target for many pharmacological treatments for depression and anxiety.

208. (B) Decarboxylation of histidine
Histamine is a powerful biological amine involved in local immune responses and gastric acid secretion. It is produced by the decarboxylation of the amino acid histidine in a reaction catalyzed by histidine decarboxylase. This enzyme requires pyridoxal phosphate as a cofactor. Histamine is stored in mast cells and basophils and is released during allergic reactions, where it causes vasodilation and increased vascular permeability, contributing to the symptoms of inflammation and allergy.

209. (B) Succinyl-CoA and Glycine
The synthesis of porphyrins, which are the fundamental building blocks of heme, starts with the condensation of succinyl-CoA and the amino acid glycine. This reaction is catalyzed by the mitochondrial enzyme delta-aminolevulinate (ALA) synthase and is the rate-limiting step of the entire heme biosynthetic pathway. Eight molecules each of succinyl-CoA and glycine are required to form the four pyrrole rings that ultimately compose the mature porphyrin ring system.

210. (A) P-3, Q-4, R-1, S-2
Arginine is the precursor for nitric oxide, while tyrosine is the starting material for the pigment melanin. The synthesis of creatine requires three amino acids: arginine, glycine, and methionine. Additionally, the essential amino acid tryptophan can be converted into the vitamin niacin in the liver. These diverse pathways illustrate the vital role of amino acids as precursors for many critical bioactive compounds beyond their function in proteins.

211. (A) Ornithine
The polyamines spermidine and spermine are synthesized starting from ornithine, which is first decarboxylated by ornithine decarboxylase to form putrescine. This initial step is highly regulated and is critical for cell growth and DNA stabilization. Subsequent additions of aminopropyl groups to putrescine lead to the formation of spermidine and then spermine. These polyamines carry multiple positive charges at physiological pH, allowing them to interact strongly with negatively charged nucleic acids.

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212. (D) It donates an aminopropyl group after being decarboxylated.
In the biosynthesis of polyamines, S-adenosylmethionine (SAM) does not serve as a methyl donor. Instead, it undergoes decarboxylation to form decarboxylated SAM. This molecule then donates an aminopropyl group to putrescine to form spermidine, and subsequently to spermidine to form spermine. This unique reaction involves the transfer of a three-carbon nitrogen-containing unit rather than a one-carbon unit, illustrating the versatile role of SAM in various cellular biosyntheses.

213. (A) Arginine, Glycine, Methionine
The synthesis of creatine is a multi-organ process involving three amino acids. In the kidney, arginine and glycine react to form guanidinoacetate. This intermediate is then transported to the liver, where it is methylated by S-adenosylmethionine to produce creatine. Creatine is subsequently released into the blood and taken up by muscle and brain tissue, where it is phosphorylated to form the high-energy reserve molecule, creatine phosphate.

214. (A) delta-Aminolevulinate (ALA) synthase
Delta-Aminolevulinate synthase is the primary rate-limiting and committed enzyme in the

heme biosynthetic pathway. Located in the mitochondria, it catalyzes the condensation of succinyl-CoA and glycine to form ALA. The enzyme is strictly regulated by feedback inhibition from heme, its final product. In the liver, heme regulates both the synthesis and the mitochondrial import of the enzyme, ensuring that heme production matches the metabolic requirements of the cell.

215. (B) Tyrosine
The thyroid hormones, triiodothyronine (T3) and thyroxine (T4), are synthesized by the iodination and coupling of tyrosine residues within the large protein thyroglobulin. This process occurs in the follicular lumen of the thyroid gland and is catalyzed by thyroid peroxidase. After iodination, specific tyrosine rings are linked together. The mature hormones are eventually released from thyroglobulin by proteolytic cleavage and secreted into the blood to regulate metabolism throughout the body.

216. (A) NO synthase; producing Citrulline
Nitric oxide is synthesized from the amino acid L-arginine by a family of enzymes known as nitric oxide synthases (NOS). The reaction involves a complex five-electron oxidation that requires oxygen and NADPH. Along with the production of the gaseous signaling molecule nitric oxide, the reaction yields the amino acid citrulline as a byproduct. NO acts as a critical regulator of vascular tone, neurotransmission, and the immune response by activating soluble guanylate cyclase.

217. (A) 5-Phosphoribosyl-1-pyrophosphate (PRPP)
In the de novo synthesis of purine nucleotides, the nine-atom purine ring is built in a stepwise fashion directly onto the C-1 position of 5-phosphoribosyl-1-pyrophosphate (PRPP). This ribose-5-phosphate donor provides the foundational scaffold for the assembly. The process involves eleven enzymatic steps where carbon and nitrogen atoms from various donors are added to the ribose until the first mature purine nucleotide, inosine monophosphate, is fully formed.

218. (B) Glycine, Aspartate, Glutamine
The purine ring is assembled using atoms donated from three specific amino acids. Glutamine provides two nitrogen atoms, glycine contributes two carbons and one nitrogen, and aspartate donates one nitrogen atom. The remaining carbon atoms are supplied by carbon dioxide and one-carbon units carried by tetrahydrofolate. This metabolic requirement highlights the deep integration of amino acid, carbohydrate, and one-carbon metabolism in the production of the building blocks for DNA and RNA.

219. (A) Inosine monophosphate (IMP)
Inosine monophosphate is the first fully formed purine nucleotide produced in the de novo biosynthetic pathway. It contains the purine base hypoxanthine. IMP serves as the essential branch point from which the other two major purine nucleotides, adenosine monophosphate and guanosine monophosphate, are synthesized. The conversion of IMP to either AMP or GMP is specifically regulated by the availability of the other nucleotide, ensuring a balanced pool of purines for cellular needs.

220. (B) I, II, III and IV
All statements regarding pyrimidine biosynthesis are correct. Unlike purines, the pyrimidine ring is first synthesized as orotate and then attached to PRPP. In mammals, the cytosolic enzyme carbamoyl phosphate synthetase II is the primary regulatory step. Aspartate and carbamoyl phosphate provide the atoms for the ring. Finally, uridine monophosphate (UMP) is the first fully formed nucleotide, which is subsequently converted into other pyrimidine species like CTP and TTP.

221. (A) CPS II uses glutamine as a nitrogen donor and does not require N-acetylglutamate.
Carbamoyl phosphate synthetase II is a cytosolic enzyme dedicated to pyrimidine biosynthesis, distinguishing it from the mitochondrial CPS I used in the urea cycle. CPS II utilizes the amide nitrogen of glutamine rather than free ammonia and does not require N-acetylglutamate for activation. Instead, it is regulated by allosteric effectors within the pyrimidine pathway, being inhibited by UTP and activated by PRPP, ensuring the rate of synthesis matches the demand for nucleotides.

222. (A) Hypoxanthine-guanine phosphoribosyl transferase (HGPRT)
Hypoxanthine-guaninephosphoribosyltransferase is a key enzyme in the purine salvage pathway. It catalyzes the transfer of the phosphoribosyl group from PRPP to the free purine bases

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hypoxanthine and guanine, regenerating inosine monophosphate and guanosine monophosphate, respectively. This salvage mechanism is energetically much more efficient than de novo synthesis and is particularly important in tissues like the brain that have a high demand for nucleotides but limited de novo capacity.

223. (A) Ribonucleotide reductase
Ribonucleotide reductase is the enzyme responsible for the conversion of all four ribonucleotides into their corresponding deoxyribonucleotides. It catalyzes the reduction of the hydroxyl group at the C-2' position of the ribose sugar to a hydrogen atom. This reaction is the only known pathway for the de novo synthesis of deoxyribonucleotides and is therefore essential for DNA replication and repair. The enzyme's activity is tightly regulated to maintain balanced dNTP pools.

224. (C) Diphosphate (NDP)
In most organisms, including humans, ribonucleotide reductase specifically acts on ribonucleoside diphosphates (ADP, GDP, CDP, and UDP) as substrates. The enzyme reduces these to the corresponding deoxyribonucleoside diphosphates (dADP, dGDP, dCDP, and dUDP). Once formed, these deoxy-intermediates are subsequently phosphorylated to the triphosphate form (dNTPs) by nucleoside diphosphate kinases, making them available for incorporation into DNA by DNA polymerases during the synthesis phase of the cell cycle.

225. (B) N5,N10-Methylenetetrahydrofolate
The synthesis of deoxythymidine monophosphate (dTMP) from dUMP is catalyzed by the enzyme thymidylate synthase. This reaction requires the one-carbon donor N5,N10-methylenetetrahydrofolate, which provides both the methyl group and the reducing equivalents needed for the conversion. During the reaction, the folate cofactor is oxidized to dihydrofolate. For the pathway to continue, dihydrofolate must be reduced back to tetrahydrofolate and remethylated, making this process a critical target for several chemotherapeutic agents.

226. (A) It competitively inhibits the dihydrofolate reductase enzyme.
Methotrexate is a folate analog that acts as a potent competitive inhibitor of the enzyme dihydrofolate reductase. By blocking this enzyme, methotrexate prevents the regeneration of tetrahydrofolate from dihydrofolate. This leads to a depletion of the one-carbon donors required for the synthesis of purine nucleotides and dTMP. Because rapidly dividing cancer cells have a high demand for DNA synthesis, they are particularly sensitive to this interruption in nucleotide metabolism.

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227. (B) ATP
The activity of ribonucleotide reductase is controlled by two distinct allosteric sites. The primary activity site determines whether the enzyme is active or inactive; binding of ATP at this site stimulates the overall activity, while binding of dATP serves as a potent inhibitor. This ensures that the production of deoxyribonucleotides is synchronized with the energy status of the cell and prevents the wasteful overproduction of dNTPs when their levels are already high.

228. (C) Orotate (Orotic acid)
Orotic acid is the first cyclic intermediate formed in the pyrimidine biosynthetic pathway before it is attached to the ribose sugar. In individuals with a genetic deficiency in the enzyme UMP synthase, orotate cannot be converted into UMP. This leads to a massive accumulation and urinary excretion of orotic acid, a condition known as orotic aciduria. The disease is characterized by megaloblastic anemia and growth retardation due to the failure of pyrimidine nucleotide synthesis.

229. (A) Uric acid
In humans, great apes, and Dalmatians, the final metabolic product of purine catabolism is uric acid. While most other mammals further oxidize uric acid to the more soluble allantoin, humans lack the functional enzyme uricase. Uric acid is relatively insoluble and is excreted by the kidneys. If its production exceeds the capacity for excretion, it can accumulate in the blood and tissues, potentially leading to the formation of crystals and clinical disease.

230. (B) Xanthine oxidase
Xanthine oxidase is a molybdenum-containing enzyme that catalyzes the final two steps of purine catabolism. It first oxidizes hypoxanthine to xanthine and then further oxidizes xanthine to uric acid. During these reactions, the enzyme transfers electrons to molecular oxygen,

producing hydrogen peroxide as a byproduct. Because it is responsible for the production of uric acid, xanthine oxidase is a major therapeutic target for managing conditions characterized by hyperuricemia, such as gout.

231. (C) Hyperuricemia leading to the precipitation of sodium urate crystals
Gout is a painful inflammatory condition caused by chronically high levels of uric acid in the blood, known as hyperuricemia. When the concentration of uric acid exceeds its solubility limit, it precipitates as needle-like crystals of monosodium urate in the joints and soft tissues. These crystals trigger an intense immune response, leading to episodes of severe joint pain, swelling, and redness. Long-term management involves reducing uric acid production or increasing its excretion.

232. (A) It acts as a competitive inhibitor and suicide substrate for xanthine oxidase.
Allopurinol is a structural analog of hypoxanthine used to treat gout by lowering uric acid levels. It functions as a competitive inhibitor of xanthine oxidase. Once bound, the enzyme converts allopurinol into oxypurinol, which remains tightly and irreversibly bound to the enzyme's active site. This "suicide inhibition" effectively shuts down the enzyme, reducing the production of uric acid and leading to an accumulation of the more soluble precursors hypoxanthine and xanthine.

233. (B) Hypoxanthine-guanine phosphoribosyl transferase (HGPRT)
Lesch-Nyhan syndrome is a rare X-linked recessive disorder caused by a near-complete deficiency of the salvage enzyme HGPRT. Without this enzyme, the cell cannot recycle hypoxanthine and guanine back into nucleotides. This results in severe neurological symptoms, intellectual disability, and characteristic self-mutilating behavior. Additionally, the failure of the salvage pathway leads to massive overproduction of uric acid, causing early-onset gout and renal stones in affected individuals.

234. (B) It prevents salvage, leading to excess PRPP and de novo synthesis.
A deficiency in HGPRT causes uric acid overproduction through two mechanisms. First, the lack of purine salvage leads to an accumulation of its substrate, PRPP, which is a potent activator of the de novo purine synthesis pathway. Second, the decreased levels of salvaged IMP and GMP remove the feedback inhibition on the early steps of de novo synthesis. Together, these effects result in a massive and uncontrolled flux through the purine biosynthetic and catabolic pathways.

235. (A) Adenosine deaminase (ADA)
Adenosine deaminase deficiency is one of the primary causes of severe combined immunodeficiency (SCID). ADA is an enzyme in the purine catabolic pathway that converts adenosine to inosine. When this enzyme is absent, adenosine and deoxyadenosine accumulate to toxic levels in the blood. This condition is particularly damaging to lymphocytes, the cells responsible for the adaptive immune response, leaving affected individuals extremely vulnerable to life-threatening infections from a very young age.

236. (B) Accumulation of dATP inhibits ribonucleotide reductase activity.
In ADA deficiency, the high levels of deoxyadenosine are phosphorylated by cellular kinases to form dATP. Excess dATP acts as a potent allosteric inhibitor of ribonucleotide reductase, the enzyme required to produce all four deoxyribonucleotides for DNA synthesis. This inhibition prevents lymphocytes from proliferating in response to antigens, effectively shutting down the immune system. The resulting lack of T and B cells leads to the characteristic immunodeficiency observed in these patients.

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237. (C) Pyrimidine degradation produces highly water-soluble intermediates.
Pyrimidine catabolism differs fundamentally from purine catabolism in the nature of its end products. While purines are degraded to the relatively insoluble uric acid, pyrimidines are broken down into highly water-soluble molecules such as beta-alanine and beta-aminoisobutyrate. These products can be easily excreted in the urine or further metabolized by the cell. Consequently, disorders of pyrimidine catabolism are rarely associated with the clinical crystal deposition problems seen in purine metabolism disorders.

238. (B) They are converted into Acetyl-CoA and Succinyl-CoA, feeding into the TCA cycle.
The carbon atoms from pyrimidine degradation are efficiently recycled into central metabolism.

Specifically, the breakdown of uracil and cytosine yields beta-alanine, which can eventually be converted into acetyl-CoA. The degradation of thymine produces beta-aminoisobutyrate, which can be further processed into succinyl-CoA. Both acetyl-CoA and succinyl-CoA enter the tricarboxylic acid cycle to be oxidized for energy, demonstrating that pyrimidines serve as a minor but useful fuel source for the cell.

239. (A) Uracil
The degradation of the pyrimidine base cytosine begins with a deamination reaction to form uracil. This reaction is catalyzed by the enzyme cytosine deaminase (or as a nucleoside by cytidine deaminase). Once uracil is formed, it enters the common pyrimidine catabolic pathway where the ring is opened and further reduced to produce beta-alanine, CO2, and ammonia. This initial deamination is a necessary step to funnel cytosine into the standard breakdown sequence for pyrimidines.

240. (A) AMP, Adenosine, Inosine, Hypoxanthine, Xanthine, Uric acid
The degradation of adenosine monophosphate to uric acid follows a logical sequence of dephosphorylation and deamination steps. First, AMP is converted to adenosine, which is then deaminated to inosine. Inosine is then cleaved to release the free purine base hypoxanthine. Finally, xanthine oxidase sequentially oxidizes hypoxanthine to xanthine and then to uric acid. This entire pathway ensures the gradual breakdown of purine nucleotides into the final excretory product in humans.

241. (B) Glycogenesis and lipogenesis
In the well-fed state, the liver plays a central role in managing the surplus of dietary glucose. High insulin levels promote the storage of glucose as glycogen through the glycogenesis pathway. Once glycogen stores are saturated, excess glucose is converted into acetyl-CoA and subsequently into fatty acids via lipogenesis. These fatty acids are then esterified to form triglycerides, which are packaged into VLDLs and exported to adipose tissue for long-term storage.

242. (C) It upregulates enzymes required to utilize circulating ketone bodies.
During prolonged starvation, the brain undergoes a significant metabolic shift to preserve body protein. Normally, the brain relies almost exclusively on glucose. However, as glucose becomes scarce and blood ketone levels rise, the brain upregulates the enzymes necessary to oxidize beta-hydroxybutyrate and acetoacetate. While it never completely stops using glucose, the ability to derive up to seventy percent of its energy from ketone bodies significantly reduces the need for gluconeogenesis from muscle-derived amino acids.

243. (B) From the reduction of dihydroxyacetone phosphate (DHAP) generated by glycolysis.
Adipose tissue lacks the enzyme glycerol kinase, meaning it cannot recycle the glycerol released during lipolysis to synthesize new triglycerides. Instead, it must obtain glycerol-3-phosphate from the glycolytic intermediate dihydroxyacetone phosphate. This process is catalyzed by glycerol-3-phosphate dehydrogenase and requires NADH. Because this pathway depends on ongoing glucose metabolism, triglyceride synthesis in fat cells is only highly active when insulin levels are elevated and glucose uptake is stimulated.

244. (A) Muscle lacks the enzyme glucose-6-phosphatase.
Skeletal muscle stores significant amounts of glycogen, but this energy is reserved exclusively for its own use. Muscle cells lack the enzyme glucose-6-phosphatase, which is required to remove the phosphate group and release free glucose into the bloodstream. Instead, the glucose-6-phosphate derived from muscle glycogenolysis enters the glycolytic pathway to provide ATP for contraction. This ensures that the muscle has an immediate and dedicated fuel supply during physical activity without depleting systemic blood sugar.

245. (B) Hepatic glycogenolysis
During the initial stages of fasting, the liver maintains blood glucose levels primarily through the breakdown of its glycogen stores. Glycogen phosphorylase is activated in response to glucagon, releasing glucose-1-phosphate, which is then converted to glucose-6-phosphate and finally to free glucose. While gluconeogenesis begins to ramp up early in fasting, glycogenolysis provides the bulk of the circulating glucose until the liver's glycogen reserves are depleted, typically within twelve to twenty-four hours.

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246. (D) Insulin
Insulin is the primary anabolic hormone secreted by the pancreas in response to rising blood glucose levels after a meal. It promotes the uptake of glucose into muscle and adipose tissue and stimulates the synthesis of glycogen, proteins, and lipids. Simultaneously, insulin inhibits catabolic pathways such as gluconeogenesis, glycogenolysis, and lipolysis. By coordinating these processes, insulin ensures that dietary nutrients are efficiently stored and that blood sugar levels are maintained within a narrow range.

247. (A) Elevated acetyl-CoA and citrate inhibit specific glycolytic enzymes.
The Randle cycle, or glucose-fatty acid cycle, describes how the oxidation of fatty acids inhibits glucose utilization in muscle. High rates of beta-oxidation produce an excess of acetyl-CoA and NADH, which inhibits the pyruvate dehydrogenase complex. Additionally, the resulting accumulation of citrate in the cytosol potently inhibits phosphofructokinase-1, the rate-limiting enzyme of glycolysis. These regulatory mechanisms prioritize the use of fats for energy when they are available, sparing glucose for tissues like the brain.

248. (B) I, II and III
All statements regarding the kidney's role during starvation are correct. During prolonged fasting, the kidney contributes up to half of the total glucose production via gluconeogenesis. It utilizes glutamine, producing alpha-ketoglutarate for the pathway and releasing ammonia as a byproduct. The excretion of this ammonia into the urine is vital, as it acts as a buffer to neutralize the acidic ketone bodies, thereby preventing severe systemic acidosis and maintaining ionic balance.

249. (C) Anaerobic glycolysis ending in lactate
Mature red blood cells lack mitochondria, nuclei, and other organelles. Because they lack mitochondria, they cannot perform the citric acid cycle or oxidative phosphorylation. Consequently, erythrocytes rely entirely on anaerobic glycolysis for their energy needs, converting glucose to lactate to generate two molecules of ATP per glucose molecule. The resulting lactate is released into the blood and transported to the liver, where it can be recycled back into glucose through the Cori cycle.

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250. (A) P-2, Q-1, R-4, S-3
Different tissues have distinct fuel preferences to optimize energy efficiency. The brain requires a constant supply of glucose and utilizes aerobic pathways. Resting skeletal muscle and heart muscle rely heavily on the oxidation of fatty acids for their baseline energy needs. Red blood cells, lacking mitochondria, are restricted to anaerobic glycolysis. Understanding these tissue-specific metabolic profiles is essential for comprehending how the body integrates its energy resources during various physiological states.

251. (A) Epinephrine
Epinephrine, often called adrenaline, is the "fight or flight" hormone released by the adrenal medulla during acute stress. It rapidly prepares the body for physical activity by stimulating the breakdown of glycogen in the liver and muscle and promoting lipolysis in adipose tissue to release free fatty acids. In the liver, it also enhances gluconeogenesis. These actions collectively increase the availability of glucose and fatty acids in the blood to meet the sudden energy demands.

252. (A) It acts as an energy sensor, switching on ATP-generating pathways.
AMP-activated protein kinase (AMPK) is a vital cellular energy sensor that is activated when the ATP-to-AMP ratio falls, signaling an energy deficit. Once active, AMPK phosphorylates various targets to switch off energy-consuming biosynthetic pathways, such as fatty acid and cholesterol synthesis. Simultaneously, it promotes energy-generating processes like glucose uptake, fatty acid oxidation, and mitochondrial biogenesis. This coordinated response helps the cell restore its energy balance and survive under metabolic stress.

253. (B) A ligand that binds to a receptor and triggers a biological response
In the context of cell signaling, an agonist is a molecule, often a hormone or neurotransmitter, that binds to a specific receptor and induces a conformational change that activates a downstream signaling cascade. This binding effectively "turns on" the biological response associated with that receptor. Agonists can be endogenous molecules or pharmacological agents designed to mimic or enhance the effects of natural ligands in various therapeutic applications.

254. (A) Seven transmembrane alpha-helices
G-protein coupled receptors are a massive family of membrane proteins characterized by a single polypeptide chain that traverses the lipid bilayer seven times. These seven transmembrane regions are alpha-helices and form a structural bundle. The extracellular loops provide the binding site for ligands, while the intracellular loops and C-terminus interact with the heterotrimeric G-proteins to initiate signal transduction. this conserved structural motif is a fundamental feature across all GPCR classes.

255. (A) It promotes the exchange of bound GDP for GTP on the alpha subunit.
When a GPCR is activated by its ligand, it undergoes a conformational change that allows it to interact with an inactive heterotrimeric G-protein. The receptor acts as a guanine nucleotide exchange factor, inducing the G-protein alpha subunit to release its bound GDP and accept a molecule of GTP. This exchange triggers the dissociation of the alpha subunit from the beta-gamma dimer, allowing both components to activate downstream effector enzymes or ion channels.

256. (A) Alpha
In the heterotrimeric G-protein complex, the alpha subunit is the component that possesses intrinsic GTPase activity. This enzymatic function allows the subunit to hydrolyze its bound GTP into GDP and inorganic phosphate. The GTPase activity acts as a built-in molecular clock that determines the duration of the signaling event. Once the GTP is hydrolyzed, the alpha subunit returns to its inactive conformation and reassociates with the beta-gamma dimer, terminating the signal.

257. (B) The alpha subunit hydrolyzes its bound GTP to the GDP form.
The termination of a G-protein signaling event is primarily driven by the internal GTPase activity of the alpha subunit. By converting the active GTP-bound form into the inactive GDP-bound form, the alpha subunit undergoes a conformational change that causes it to dissociate from its effector and reunite with the beta-gamma subunits. This auto-inactivation ensures that the cellular response is transient and proportional to the duration of the ligand-receptor interaction at the membrane.

258. (A) G-alpha-s
The G-alpha-s subunit is a specific type of G-protein alpha subunit that, when bound to GTP, stimulates the membrane-bound enzyme adenylate cyclase. This activation leads to a rapid increase in the intracellular concentration of the second messenger cyclic AMP. This signaling pathway is used by many hormones, such as glucagon and epinephrine, to trigger various physiological responses, including the breakdown of glycogen and the mobilization of stored energy reserves within the cell.

259. (A) It irreversibly activates G-alpha-s by inhibiting its intrinsic GTPase activity.
Cholera toxin is an enzyme that catalyzes the ADP-ribosylation of the G-alpha-s subunit. This covalent modification permanently inhibits the subunit's intrinsic GTPase activity, locking it in the active, GTP-bound state. As a result, adenylate cyclase remains constitutively active, leading to abnormally high and sustained levels of cAMP in intestinal epithelial cells. This causes the massive efflux of chloride ions and water into the gut lumen, resulting in the severe watery diarrhea characteristic of cholera.

260. (A) Both A and R are true and R is the correct explanation of A.
Receptor tyrosine kinases are a class of cell surface receptors that function through dimerization. Upon binding their specific ligand, two individual receptor monomers come together to form a stable dimer. This proximity allows the intracellular kinase domains to cross-phosphorylate each other on specific tyrosine residues. This autophosphorylation creates docking sites for various downstream signaling proteins, effectively initiating the intracellular cascade that regulates processes like growth, differentiation, and metabolism.

261. (A) Receptor tyrosine kinase
The insulin receptor is a well-characterized member of the receptor tyrosine kinase family. Unlike many other RTKs that exist as monomers until ligand binding, the insulin receptor is a pre-formed disulfide-linked heterotetramer consisting of two alpha and two beta subunits. When insulin binds to the extracellular alpha subunits, it triggers a conformational change that activates the tyrosine kinase activity of the intracellular beta subunits, leading to autophosphorylation and the recruitment of signaling molecules.

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262. (A) Ras
Ras is a family of small, monomeric GTPases that play a central role in transmitting signals from activated receptor tyrosine kinases to the cell nucleus. Ras acts as a molecular switch, cycling between an active GTP-bound state and an inactive GDP-bound state. When activated, Ras initiates the MAP kinase cascade, which ultimately regulates gene expression and cell division. Mutations that lock Ras in the active state are frequently found in many types of human cancers.

263. (A) In the cytosol or nucleus, acting as transcription factors
Steroid hormones, such as estrogen and cortisol, are lipophilic and can diffuse easily across the plasma membrane. Their receptors are located within the cytosol or the nucleus of the target cell. Upon hormone binding, the receptor undergoes a conformational change and translocates to the nucleus if it was not already there. The hormone-receptor complex then binds to specific DNA sequences, acting directly as a transcription factor to regulate the expression of target genes.

264. (A) They cleave phosphodiester bonds to degrade secondary messengers like cAMP and cGMP.
Phosphodiesterases are critical regulatory enzymes that terminate signal transduction by hydrolyzing the second messengers cyclic AMP and cyclic GMP into their inactive forms, AMP and GMP. By controlling the rate of degradation of these messengers, PDEs determine the intensity and duration of the signaling response. Inhibitors of specific PDE isoforms, such as those used to treat erectile dysfunction or inflammatory conditions, act by prolonging the presence of these signaling molecules.

265. (A) Protein kinase A (PKA)
Cyclic AMP acts as a second messenger primarily by activating Protein kinase A, also known as cAMP-dependent protein kinase. PKA is a multifunctional enzyme that phosphorylates a wide variety of target proteins on serine and threonine residues. These targets include metabolic enzymes, ion channels, and transcription factors like CREB. By phosphorylating these proteins, PKA mediates the diverse effects of hormones that utilize the cAMP signaling pathway to alter cellular behavior and gene expression.

266. (B) By binding to regulatory subunits to free active catalytic subunits.
In its inactive state, Protein kinase A exists as a heterotetramer consisting of two regulatory subunits and two catalytic subunits. When the concentration of cyclic AMP rises, four cAMP molecules bind to the regulatory subunits, causing a conformational change that results in their dissociation from the catalytic subunits. The freed catalytic subunits are now enzymatically active and can move throughout the cell to phosphorylate their specific target proteins, thus propagating the hormone's signal.

267. (B) G-alpha-q
The effector enzyme phospholipase C-beta is typically activated by the G-alpha-q class of G-protein alpha subunits. When a ligand binds to a G-alpha-q-coupled receptor, the activated alpha subunit stimulates PLC to hydrolyze the membrane phospholipid phosphatidylinositol 4,5-bisphosphate. This pathway is a fundamental mechanism for many hormones and neurotransmitters, such as vasopressin and acetylcholine, to trigger intracellular responses by generating multiple second messengers that increase calcium levels and activate protein kinases.

268. (A) Inositol 1,4,5-trisphosphate (IP3) and Diacylglycerol (DAG)
Phospholipase C catalyzes the cleavage of the membrane lipid phosphatidylinositol 4,5-bisphosphate into two distinct second messengers: inositol 1,4,5-trisphosphate and diacylglycerol. IP3 is a water-soluble molecule that diffuses into the cytosol to regulate calcium release, while DAG remains embedded in the plasma membrane. Both molecules play essential roles in propagating the signal, demonstrating how a single receptor-ligand interaction can branched into multiple downstream pathways to coordinate a complex cellular response.

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269. (D) It binds to ER receptors to trigger the release of calcium ions.
Inositol 1,4,5-trisphosphate functions as a mobile second messenger that travels from the plasma membrane to the endoplasmic reticulum. Once there, it binds to specific IP3-gated calcium channels in the ER membrane, causing them to open and release stored calcium ions into the cytosol. This rapid increase in cytosolic calcium concentration acts as a further signal to

activate various calcium-dependent proteins and enzymes, mediating a wide range of physiological processes like muscle contraction and secretion.

270. (A) Protein kinase C (PKC)
Diacylglycerol, which remains in the plasma membrane after its formation, acts as a second messenger to activate Protein kinase C. For full activation, most PKC isoforms also require the presence of calcium ions, which are released from the ER by IP3. DAG increases the affinity of PKC for the membrane and for calcium. Once activated, PKC phosphorylates numerous target proteins, regulating various aspects of cell growth, differentiation, and metabolism within the cell.

271. (A) Calmodulin
Calmodulin is a small, highly conserved acidic protein that serves as a primary intracellular receptor for calcium ions. It has no intrinsic enzymatic activity but undergoes a major conformational change upon binding calcium. The resulting calcium-calmodulin complex then interacts with and activates a wide variety of target proteins, including kinases, phosphatases, and ion pumps. This allows calmodulin to translate changes in calcium concentration into diverse physiological responses across different cell types and tissues.

272. (D) Four
Calmodulin contains four specialized high-affinity calcium-binding sites known as EF-hands. These sites are arranged in two pairs, one pair at each end of the protein's dumbbell-shaped structure. When the cytosolic calcium concentration rises, all four sites can become occupied, triggering the conformational change that allows calmodulin to wrap around and activate its target enzymes. This cooperative binding makes the protein highly sensitive to small fluctuations in the levels of intracellular calcium ions.

273. (A) Guanylate cyclase
Cyclic GMP is synthesized from GTP by the enzyme guanylate cyclase. This enzyme exists in two forms: a membrane-bound form that acts as a receptor for peptide hormones like atrial natriuretic peptide, and a soluble form that is activated by the gaseous signaling molecule nitric oxide. Once produced, cGMP act as a second messenger to regulate ion channels and activate cGMP-dependent protein kinases, playing vital roles in cardiovascular homeostasis, vision, and fluid balance.

274. (B) I, II and III
All statements regarding the NO-cGMP signaling pathway are correct. Nitric oxide is a membrane-permeable gas that activates soluble guanylate cyclase within smooth muscle cells. This leads to an increase in intracellular cGMP levels, which in turn activates Protein kinase G. PKG then phosphorylates several targets to decrease cytosolic calcium and reduce the sensitivity of the contractile machinery, resulting in muscle relaxation and vasodilation of the blood vessels, which lowers blood pressure.

275. (A) Its levels drop rapidly due to the activation of a phosphodiesterase.
In the visual transduction pathway, light activates the GPCR rhodopsin, which then stimulates the G-protein transducin. Transducin activates a specific cGMP phosphodiesterase that rapidly hydrolyzes cGMP to GMP. This drop in cGMP levels causes cGMP-gated sodium channels in the photoreceptor membrane to close, leading to hyperpolarization of the cell. This electrical signal is then transmitted to the brain, representing the first step in the conversion of light into a visual perception.

276. (B) The receptor is bound by beta-arrestin and uncoupled from G-proteins.
Signal desensitization is a process that limits the duration of a cellular response even in the continued presence of a ligand. For GPCRs, this often involves phosphorylation of the receptor by G-protein coupled receptor kinases. This phosphorylation promotes the binding of a protein called beta-arrestin, which physically blocks the receptor from interacting with more G-proteins. Arrestin binding can also trigger the internalization of the receptor via endocytosis, reducing the number of receptors on the cell surface.

277. (A) Glucose-6-phosphatase
Von Gierke's disease, or Glycogen Storage Disease Type I, is caused by a deficiency in the enzyme glucose-6-phosphatase. This enzyme is essential for releasing free glucose into the blood from both glycogenolysis and gluconeogenesis in the liver and kidneys. Without it, patients suffer from severe fasting hypoglycemia, as they cannot mobilize their glucose stores. Additionally,

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the buildup of glucose-6-phosphate leads to hepatomegaly, lactic acidosis, hyperlipidemia, and hyperuricemia due to the diversion into other metabolic pathways.

278. (C) Lysosomal alpha-1,4-glucosidase (acid maltase)
Pompe's disease is a unique glycogen storage disorder because it results from a defect in the lysosomal enzyme alpha-1,4-glucosidase, rather than a cytosolic pathway. This enzyme normally degrades small amounts of glycogen that become trapped within lysosomes. When deficient, glycogen accumulates massively within these organelles, eventually disrupting cellular architecture and function. This disease primarily affects cardiac and skeletal muscle, leading to severe cardiomyopathy and muscle weakness, often presenting in infancy with fatal consequences.

279. (B) Muscle glycogen phosphorylase
McArdle's disease, or Glycogen Storage Disease Type V, is caused by a deficiency in the muscle-specific isoform of glycogen phosphorylase, also known as myophosphorylase. Because the enzyme is absent, muscle cells cannot break down glycogen to provide glucose for ATP production during exercise. This results in severe exercise intolerance, muscle pain, and cramping. Interestingly, patients often experience a "second wind" phenomenon where they can continue exercise once the body switches to using blood-borne fatty acids and glucose.

280. (B) Galactose-1-phosphate uridyltransferase (GALT)
Classic galactosemia is the most common and severe form of the disorder, caused by a deficiency in galactose-1-phosphate uridyltransferase. This enzyme is required to convert galactose-1-phosphate and UDP-glucose into UDP-galactose and glucose-1-phosphate. Without this activity, galactose-1-phosphate and galactose accumulate to toxic levels in the blood and tissues. The condition is a medical emergency in neonates, as ingestion of breast milk or formula leads to rapid liver failure, sepsis, and neurological damage.

281. (A) Galactitol (Dulcitol)
In individuals with galactosemia, the excess circulating galactose is shunted into an alternative pathway where the enzyme aldose reductase reduces it to the sugar alcohol galactitol. Unlike galactose, galactitol is not further metabolized and cannot easily cross cell membranes. In the lens of the eye, galactitol accumulates and exerts a powerful osmotic effect, drawing in water and causing the swelling and protein denaturation that leads to the formation of cataracts, often early in life.

282. (B) LDL receptor
Familial hypercholesterolemia is most frequently caused by mutations in the gene encoding the LDL receptor. This protein is responsible for the clearance of low-density lipoprotein particles from the blood through receptor-mediated endocytosis in the liver. A deficiency in functional receptors leads to a significant increase in circulating LDL cholesterol, which deposits in the skin and tendons as xanthomas and promotes the premature development of atherosclerosis and coronary heart disease, even in early childhood.

283. (A) Tay-Sachs disease
Tay-Sachs disease is a lysosomal storage disorder caused by a deficiency in the enzyme hexosaminidase A. This enzyme is required to degrade GM2 gangliosides in the brain. Without it, these complex lipids accumulate within lysosomes, causing progressive and irreversible destruction of nerve cells. The disease is characterized by developmental regression, seizures, and blindness. The "cherry-red spot" on the retina is a classic diagnostic hallmark, representing the accumulation of gangliosides in the surrounding ganglion cells.

284. (A) Beta-glucocerebrosidase
Gaucher's disease is the most prevalent lysosomal storage disorder and is caused by a deficiency in the enzyme beta-glucocerebrosidase. This enzyme is responsible for cleaving the sugar glucose from the lipid glucocerebroside. The accumulation of this lipid occurs primarily in macrophages, which then transform into characteristic "Gaucher cells" with a crinkled paper appearance. These cells infiltrate the bone marrow, liver, and spleen, causing anemia, thrombocytopenia, hepatosplenomegaly, and skeletal abnormalities in affected individuals.

285. (A) Sphingomyelinase
Niemann-Pick disease types A and B result from a genetic deficiency in the lysosomal enzyme acid sphingomyelinase. This enzyme is essential for

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the hydrolysis of sphingomyelin into ceramide and phosphorylcholine. When deficient, sphingomyelin accumulates within lysosomes in multiple organs, particularly the liver, spleen, and brain. Type A is a severe neurodegenerative form that is fatal in early childhood, while Type B is a milder, non-neurological form characterized by significant organ enlargement and pulmonary involvement.

286. (B) Aldolase B
Hereditary fructose intolerance is a potentially life-threatening disorder caused by a deficiency in the enzyme aldolase B. This enzyme is required to cleave fructose-1-phosphate into dihydroxyacetone phosphate and glyceraldehyde. A lack of aldolase B leads to a toxic accumulation of fructose-1-phosphate, which inhibits glycogenolysis and gluconeogenesis by sequestering intracellular inorganic phosphate. This results in severe, post-prandial hypoglycemia, vomiting, and jaundice upon the ingestion of fructose, sucrose, or sorbitol in the diet.

287. (A) P-2, Q-1, R-4, S-3
Each lipid storage disease is characterized by the accumulation of a specific metabolite due to an enzyme deficiency. Tay-Sachs disease involves GM2 ganglioside, Gaucher's disease involves glucocerebroside, Niemann-Pick disease involves sphingomyelin, and Krabbe disease involves galactocerebroside. These metabolites accumulate within lysosomes and disrupt normal cellular function, particularly in the nervous system and reticuloendothelial organs, leading to the diverse clinical manifestations observed in these genetic disorders.

288. (A) Fabry's disease
Fabry's disease is distinct from most other lysosomal storage disorders because it is inherited in an X-linked recessive manner, primarily affecting males. It is caused by a deficiency in the enzyme alpha-galactosidase A, leading to the accumulation of globotriaosylceramide in the vascular endothelium and various organs. Patients typically present with episodic pain in the extremities, a characteristic skin rash called angiokeratoma, and progressive damage to the kidneys, heart, and brain throughout adulthood.

289. (A) Phenylalanine hydroxylase (PAH)
Phenylketonuria is the most common inborn error of amino acid metabolism, resulting from a deficiency in the enzyme phenylalanine hydroxylase. This enzyme normally converts the essential amino acid phenylalanine to tyrosine. The lack of PAH activity leads to dangerously high levels of phenylalanine in the blood and brain, which is neurotoxic and causes severe intellectual disability and behavioral problems if not treated from birth. Screening for PKU is a standard part of newborn testing worldwide.

290. (A) Restrict Phenylalanine; Supplement Tyrosine
The primary treatment for phenylketonuria involves a strict lifelong diet that is extremely low in phenylalanine to prevent its toxic accumulation. However, because tyrosine is normally synthesized from phenylalanine, it becomes an essential amino acid for these patients and must be supplemented to ensure adequate protein synthesis and production of catecholamines and melanin. This dietary management is crucial for supporting normal brain development and preventing the severe neurological consequences of the disease.

291. (A) Homogentisate
Alkaptonuria is caused by a deficiency in the enzyme homogentisate oxidase, which is involved in the catabolism of phenylalanine and tyrosine. This leads to the accumulation of homogentisic acid in the blood and its subsequent excretion in the urine. When exposed to air, the acid oxidizes and polymerizes into a black pigment, a diagnostic feature of the disease. Over decades, this pigment also deposits in connective tissues, causing a condition called ochronosis and severe debilitating arthritis.

292. (A) Tyrosinase
Oculocutaneous albinism Type 1 is a genetic disorder resulting from a deficiency in the enzyme tyrosinase. This enzyme is required for the first two steps of melanin biosynthesis: the hydroxylation of tyrosine to DOPA and its subsequent oxidation to dopaquinone. Without functional tyrosinase, melanocytes cannot produce the pigment melanin, leading to a complete or partial lack of pigmentation in the skin, hair, and eyes. This absence of pigment also causes significant vision problems and increased sensitivity to UV radiation.

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293. (A) Branched-chain alpha-keto acid dehydrogenase
Maple syrup urine disease is caused by a genetic defect in the branched-chain alpha-keto acid dehydrogenase complex. This large multienzyme complex is responsible for the oxidative decarboxylation of the keto acids derived from the branched-chain amino acids leucine, isoleucine, and valine. A deficiency in this complex prevents the further degradation of these molecules, leading to their toxic accumulation in the blood and brain, which causes the characteristic sweet-smelling urine and severe neurological decline in infants.

294. (A) Leucine, Isoleucine, Valine
In maple syrup urine disease, the three essential branched-chain amino acids—leucine, isoleucine, and valine—accumulate along with their corresponding alpha-keto acids in the body's fluids. Leucine is particularly neurotoxic at high levels, contributing significantly to the brain edema and neurological dysfunction seen in the disorder. The characteristic "maple syrup" or burnt sugar odor of the urine and earwax is primarily due to the presence of one of these alpha-keto acid metabolites, isoleucine's byproduct.

295. (A) Cystathionine beta-synthase
Homocystinuria is most commonly caused by a deficiency in the enzyme cystathionine beta-synthase, which requires pyridoxal phosphate as a cofactor. This enzyme normally catalyzes the condensation of homocysteine and serine to form cystathionine. When deficient, homocysteine and its precursor methionine accumulate in the blood and urine. The high levels of homocysteine interfere with the cross-linking of collagen and elastin, leading to the skeletal, ocular, and vascular complications that characterize the disease.

296. (A) Pyridoxine (B_6)
A significant proportion of patients with classic homocystinuria are "B6-responsive," meaning their condition improves with high doses of pyridoxine. Pyridoxine is the precursor to pyridoxal phosphate, the essential cofactor for the deficient enzyme cystathionine beta-synthase. By increasing the available pool of PLP, the residual enzyme activity can be enhanced enough to lower homocysteine levels and prevent the progression of clinical symptoms. This vitamin therapy is a cornerstone of management for responsive individuals.

297. (A) Fumarylacetoacetase
Tyrosinemia Type I, the most severe form of the disease, is caused by a deficiency in fumarylacetoacetase, the final enzyme in the tyrosine catabolic pathway. This leads to the accumulation of fumarylacetoacetate and its conversion into succinylacetone, a potent toxin that damages the liver and kidneys. Affected infants present with acute liver failure, renal dysfunction, and a characteristic cabbage-like odor. Treatment involves a low-protein diet and pharmacological inhibition of an earlier step in the pathway to prevent toxin formation.

298. (C) I, II, III and IV
Phenylketonuria is primarily caused by a deficiency in phenylalanine hydroxylase or its cofactor, tetrahydrobiopterin. This defect results in the accumulation of phenylalanine and its metabolites, such as phenylpyruvate, which impart a characteristic musty odor to urine. Furthermore, the lack of tyrosine synthesis leads to decreased melanin production and hypopigmentation. All these statements accurately reflect the biochemical and clinical manifestations of the condition, emphasizing the importance of both the enzyme and the cofactor for normal metabolism.

299. (A) Phenylalanine (PKU) → p-Hydroxyphenylpyruvate (Tyrosinemia II) → Homogentisate (Alkaptonuria) → Fumarylacetoacetate (Tyrosinemia I)
The tyrosine catabolic pathway involves a series of sequential enzymatic steps, each associated with a specific metabolic disorder. Phenylalanine is first converted to tyrosine; its buildup causes PKU. Tyrosine is then converted to p-hydroxyphenylpyruvate, then to homogentisate, and eventually to fumarylacetoacetate before forming final products. This sequence of metabolites correctly maps the order of the pathway and the relative position of the metabolic blocks that lead to the clinical diseases mentioned in the list.

300. (A) Both A and R are true and R is the correct explanation of A.
Patients with maple syrup urine disease cannot metabolize branched-chain amino acids properly due to a dehydrogenase complex deficiency.

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However, leucine, isoleucine, and valine are essential amino acids that the human body cannot synthesize de novo. Therefore, while dietary intake must be strictly limited to prevent toxic ketoacid accumulation, these amino acids must still be provided in sufficient quantities to support protein synthesis and growth, making dietary management a delicate balancing act for survival.

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CHAPTER 03
Enzymes, Vitamins and Hormones

2013

1. According to the IUBMB classification, which class of enzymes catalyzes the transfer of functional groups between molecules?
(A) Transferases
(B) Oxidoreductases
(C) Hydrolases
(D) Isomerases

2014

2. Which of the following is an INCORRECT representation of the Enzyme Commission (EC) numbering system?
(A) The first digit denotes the major class
(B) The second digit denotes the subclass
(C) The third digit denotes the specific substrate
(D) The fourth digit denotes the serial number

2005

3. Ligases are classified under which major IUBMB class?
(A) Class 3
(B) Class 4
(C) Class 5
(D) Class 6

2005

4. Which of the following best defines the function of an isomerase?
(A) Cleavage of bonds using water
(B) Joining of two molecules with ATP hydrolysis
(C) Addition of groups to double bonds
(D) Intramolecular rearrangement of atoms

2016

5. In enzyme nomenclature, what does a systematic name uniquely identify?
(A) The specific coenzyme or essential organic factor involved
(B) The precise chemical reaction catalyzed
(C) The organism or tissue from which it was isolated
(D) The optimal pH and temperature of the reaction

2008

6. Transaminases belong to which major enzyme class?
(A) Hydrolases
(B) Lyases
(C) Transferases
(D) Oxidoreductases

2022

7. Peptidases, which cleave peptide bonds via the addition of water, are classified as:
(A) EC 1
(B) EC 2
(C) EC 3
(D) EC 4

2008

8. Which statement is LEAST relevant to the physiological role of lyases?
(A) They require ATP hydrolysis for their primary action
(B) They form double bonds by removing groups
(C) They add groups to existing double bonds
(D) They operate non-hydrolytically

2017

9. Dehydrogenases are primarily categorized under which IUBMB class?
(A) Transferases
(B) Oxidoreductases
(C) Isomerases
(D) Ligases

2003

10. Synthetases differ from synthases because synthetases:
(A) Do not require energy
(B) Strictly require nucleoside triphosphates like ATP
(C) Belong to Class 4
(D) Only operate in anaerobic conditions

2022

11. Which of the following equations accurately relates standard free energy change (ΔG°) to the equilibrium constant (K_{eq})?
(A) $\Delta G^{\circ} = -RT\ln K_{eq}$
(B) $\Delta G^{\circ} = RT\ln K_{eq}$
(C) $\Delta G^{\circ} = -R\ln K_{eq}$
(D) $\Delta G^{\circ} = -T\ln K_{eq}$

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2007

12. Enzymes accelerate reaction rates primarily by:
(A) Lowering the overall free energy of the reaction
(B) Increasing the kinetic energy of substrates
(C) Lowering the activation energy
(D) Shifting the equilibrium towards products

2017

13. Transition state theory proposes that the transition state is:
(A) A stable intermediate with significant shelf life
(B) The final product formed during the catalytic cycle
(C) A low-energy precursor state in the ground state
(D) A transient species with the highest free energy

2015

14. Which factor does NOT influence the standard free energy change of a biochemical reaction?
(A) Temperature
(B) Pressure
(C) Presence of a catalyst
(D) Nature of reactants

2008

15. Match the items in List I with those in List II:
List I : (Thermodynamic Term)
P. Enthalpy
Q. Entropy
R. Free Energy
S. Activation Energy
List II : (Description)
1. Energy required to reach the transition state
2. Measure of system randomness
3. Total heat content
4. Energy available to do work
(A) P-2, Q-3, R-1, S-4
(B) P-3, Q-2, R-4, S-1
(C) P-4, Q-1, R-3, S-2
(D) P-1, Q-4, R-2, S-3

2011

16. In an exergonic enzymatic reaction, the free energy of the products is:
(A) Higher than the reactants
(B) Equal to the reactants
(C) Unpredictable
(D) Lower than the reactants

2008

17. The binding energy released when an enzyme interacts with its substrate is maximized at:
(A) The transition state
(B) Substrate entry
(C) Product release
(D) Apoenzyme formation

2006

18. Which statement regarding activation energy (E_a) is INCORRECT?
(A) It determines the rate of the reaction
(B) It is unaffected by temperature
(C) It dictates the equilibrium constant of the reaction
(D) It acts as a barrier to product formation

2007

19. An apoenzyme can be best defined as:
(A) An enzyme bound to its cofactor
(B) A non-protein organic molecule essential for catalysis
(C) A catalytically active metallic ion in the active site
(D) The inactive protein component of an enzyme

2024

20. The functionally active complex of an enzyme and its required cofactor is termed a:
(A) Zymogen
(B) Holoenzyme
(C) Proenzyme
(D) Isoenzyme

2004

21. Which of the following is considered an inorganic metallic cofactor?
(A) Flavin adenine dinucleotide (FAD)
(B) Magnesium (Mg^{2+})
(C) Nicotinamide adenine dinucleotide (NAD)
(D) Coenzyme A

2001

22. A coenzyme that is tightly and covalently bound to its apoenzyme is specifically called a:
(A) Prosthetic group
(B) Cosubstrate
(C) Zymogen
(D) Modulator

2017

23. Which of the following serves as a transient carrier of specific atoms or functional groups and easily dissociates from the enzyme?
(A) Prosthetic group
(B) Metalloenzyme core
(C) Cosubstrate
(D) Apoenzyme

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2010

24. Zinc ($Zn^{\{2+\}}$) is an essential cofactor for which of the following enzymes?
(A) Hexokinase
(B) Pyruvate kinase
(C) Cytochrome oxidase
(D) Carbonic anhydrase

2004

25. Which pair of enzyme component and its description is correct?
(A) Holoenzyme - Inactive protein part
(B) Apoenzyme - Active enzyme-cofactor complex
(C) Prosthetic group - Tightly bound coenzyme
(D) Cosubstrate - Covalently linked metal ion

2017

26. Which feature is characteristic of an enzyme's active site?
(A) It occupies the majority of the enzyme's total volume and mass
(B) It forms a rigid, inflexible pocket that never changes its shape
(C) It binds substrates through multiple weak interactions
(D) It interacts randomly with any metabolic intermediate in the cell

2017

27. The lock-and-key model of enzyme-substrate interaction implies that:
(A) The active site is perfectly complementary to the substrate beforehand
(B) The active site undergoes a significant shift to fit the substrate
(C) The enzyme structure is completely denatured during catalysis
(D) The substrate restricts its conformation only after binding occurs

2022

28. Which active site mapping technique utilizes chemical agents that structurally resemble the substrate but form stable covalent bonds with active site residues?
(A) X-ray crystallography
(B) Affinity labeling
(C) Site-directed mutagenesis
(D) Fluorescence spectroscopy

2019

29. The induced fit model of enzyme catalysis suggests that:
(A) The substrate induces a permanent degradation of the enzyme
(B) Any substrate can bind if it hits the enzyme hard enough
(C) The active site undergoes a conformational change upon substrate binding
(D) Coenzymes prevent structural shifts

2010

30. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Affinity labels are useful for identifying amino acid residues in an enzyme's active site.
Reason (R) : Affinity labels are unreactive structural analogs that merely compete with the substrate without covalent attachment.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2018

31. Site-directed mutagenesis is an active site mapping tool primarily used to:
(A) Determine the exact atomic weight of the enzyme molecule
(B) Directly visualize the three-dimensional protein structure
(C) Extract cofactors from the interior of the holoenzyme
(D) Substitute specific amino acids to assess their catalytic role

2005

32. Which amino acid is most frequently found acting as a general acid or base at the active site due to its pKa being near physiological pH?
(A) Alanine
(B) Histidine
(C) Leucine
(D) Glycine

2012

33. Under the steady-state assumption of Michaelis-Menten kinetics, which of the following remains constant?
(A) Total concentration of the substrate in the system
(B) The concentration of the enzyme-substrate complex $[ES]$
(C) Total amount of product formed during the time course
(D) The concentration of the free enzyme

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available for binding

2014

34. The Michaelis constant (K_m) is defined as the substrate concentration at which the reaction velocity is:
(A) Half of $V_{\max}$
(B) Equal to $V_{\max}$
(C) Independent of enzyme concentration
(D) At its theoretical maximum

2021

35. A high K_m value generally indicates:
(A) High affinity of the enzyme for its substrate
(B) Rapid product release
(C) Low affinity of the enzyme for its substrate
(D) Irreversible binding of the substrate

2009

36. Which parameter best represents the turnover number of an enzyme?
(A) K_m
(B) $V_{\max}$
(C) K_{eq}
(D) k_{cat}

2008

37. Catalytic efficiency is mathematically defined as:
(A) $\frac{V_{\max}}{K_m}$
(B) $\frac{K_m}{k_{cat}}$
(C) $\frac{k_{cat}}{K_m}$
(D) $k_{cat} \times V_{\max}$

2016

38. If an enzyme has achieved catalytic perfection, its catalytic efficiency is primarily limited by:
(A) The rate of product release
(B) The diffusion rate of the substrate
(C) The intrinsic turnover number
(D) The conformational change of the enzyme

2011

39. In the Michaelis-Menten equation, when substrate concentration $[S]$ is much greater than K_m, the initial velocity v_0 approaches:
(A) K_m
(B) Zero
(C) Half $V_{\max}$
(D) $V_{\max}$

2023

40. Which linear transformation of the Michaelis-Menten equation plots $\frac{1}{v_0}$ against $\frac{1}{[S]}$?
(A) Lineweaver-Burk plot
(B) Eadie-Hofstee plot
(C) Hanes-Woolf plot
(D) Scatchard plot

2021

41. In a Lineweaver-Burk plot, the y-intercept corresponds to:
(A) $-\frac{1}{K_m}$
(B) $\frac{K_m}{V_{\max}}$
(C) $\frac{1}{V_{\max}}$
(D) $\frac{V_{\max}}{K_m}$

2022

42. In a Lineweaver-Burk plot, the x-intercept is mathematically equivalent to:
(A) $-\frac{1}{K_m}$
(B) $\frac{1}{V_{\max}}$
(C) $\frac{K_m}{V_{\max}}$
(D) $\frac{1}{K_m}$

2001

43. Which plot yields the most statistically robust linear estimation by minimizing the distortion of errors at low substrate concentrations?
(A) Lineweaver-Burk plot
(B) Eadie-Hofstee plot
(C) Michaelis-Menten curve
(D) Hanes-Woolf plot

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2019

44. The Eadie-Hofstee plot graphs:
(A) $\frac{[S]}{v_0}$ versus $[S]$
(B) v_0 versus $\frac{v_0}{[S]}$
(C) $\frac{1}{v_0}$ versus $\frac{1}{[S]}$
(D) v_0 versus $[S]$

2021

45. Consider the following combinations regarding linear enzyme plots:
I. Lineweaver-Burk: Y-axis is $\frac{1}{v_0}$
II. Eadie-Hofstee: X-axis is $\frac{v_0}{[S]}$

III. Hanes-Woolf: Y-axis is $\frac{[S]}{v_0}$

IV. Lineweaver-Burk: Slope is $\frac{V_{max}}{K_m}$

Which of the above combination(s) is/are INCORRECT?
(A) I and III
(B) II and IV
(C) IV only
(D) I, II and III

2002

46. In the Hanes-Woolf plot, the slope of the line represents:
(A) $\frac{K_m}{V_{max}}$
(B) $\frac{1}{V_{max}}$
(C) $-K_m$
(D) $\frac{1}{K_m}$

2022

47. Which multi-substrate mechanism involves all substrates binding to the enzyme before any product is released?
(A) Sequential mechanism
(B) Ping-Pong mechanism
(C) Double-displacement mechanism
(D) Substituted-enzyme mechanism

2003

48. In an ordered sequential bisubstrate reaction:
(A) Substrates can bind in any order
(B) The first product is released before the second substrate binds
(C) There is an obligatory order for substrate binding
(D) A substituted enzyme intermediate is formed

2022

49. A Ping-Pong (double-displacement) mechanism is characterized by:
(A) Constant formation of a ternary complex
(B) Spontaneous random binding of all substrates
(C) Simultaneous release of all final products
(D) The transient covalent modification of the enzyme

2021

50. Aminotransferases typically follow which kinetic mechanism?
(A) Ordered sequential
(B) Random sequential
(C) Ping-Pong
(D) Theorell-Chance

2013

51. Which kinetic plot feature distinguishes a Ping-Pong mechanism from a sequential mechanism?
(A) Intersecting lines in a double-reciprocal plot
(B) Parallel lines in a double-reciprocal plot
(C) A single line in a double-reciprocal plot
(D) Non-linear curves in a Hanes-Woolf plot

2017

52. In a sequential multi-substrate reaction, the double-reciprocal plot of $\frac{1}{v}$ versus $\frac{1}{[A]}$ at various fixed concentrations of B yields:
(A) Lines intersecting at the y-axis
(B) Parallel lines
(C) Lines intersecting on the x-axis
(D) Lines intersecting to the left of the y-axis

2025

53. Isotope exchange at equilibrium without the requirement of all substrates being present is indicative of which mechanism?
(A) Ping-Pong
(B) Ordered sequential
(C) Random sequential
(D) Concerted

2008

54. General acid-base catalysis differs from specific acid-base catalysis because it involves:
(A) Only H^+ and OH^- ions derived from water
(B) Temporary covalent bond formation in the active site
(C) Proton transfers mediated by weak acids/bases other than water
(D) Exclusive utilization of divalent metal ions for catalysis

2011

55. In covalent catalysis, a transient covalent bond is formed between the enzyme and the substrate. This typically involves which type of group on the enzyme?
(A) Nucleophilic
(B) Electrophilic
(C) Hydrophobic
(D) Non-polar

2002

56. Metal ion catalysis can enhance the reaction rate by all of the following EXCEPT:
(A) Orienting substrates
(B) Stabilizing negative charges on reaction intermediates

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(C) Mediating redox reactions
(D) Increasing the hydration shell of the substrate

2009

57. The proximity and orientation effect in enzyme catalysis achieves rate enhancement primarily by:
(A) Increasing the entropy of the transition state
(B) Lowering the entropy of the substrates
(C) Donating protons
(D) Forming covalent intermediates

2011

58. Chymotrypsin utilizes a catalytic triad consisting of which three amino acids?
(A) Serine, Lysine, Glutamate
(B) Cysteine, Histidine, Asparagine
(C) Serine, Histidine, Asparate
(D) Threonine, Arginine, Glutamate

2011

59. In the catalytic triad of chymotrypsin, what is the specific role of the aspartate residue?
(A) It attacks the peptide bond directly to form a bond
(B) It acts as the primary nucleophile in the active site
(C) It binds the bulky aromatic side chain of the substrate
(D) It stabilizes the positive charge on histidine

2010

60. Arrange the following steps of covalent catalysis in the correct sequence:
I. Breakdown of the intermediate to release product
II. Formation of a covalent intermediate
III. Nucleophilic attack by the enzyme
IV. Regeneration of the free enzyme
Which of the following represents the correct sequence?
(A) II, III, I, IV
(B) III, II, I, IV
(C) I, III, II, IV
(D) III, I, II, IV

2012

61. Competitive inhibition is characterized by an inhibitor that binds to the:
(A) Enzyme-substrate complex only
(B) Free enzyme at the active site
(C) Allosteric site of the free enzyme
(D) Substrate molecule directly

2013

62. In the presence of a competitive inhibitor, the apparent K_m ($K_m^{\{app\}}$):
(A) Increases
(B) Decreases
(C) Remains unchanged
(D) Becomes zero

2015

63. How is V_{max} affected by pure competitive inhibition?
(A) It is increased
(B) It is decreased
(C) It remains unchanged
(D) It is halved

2005

64. An uncompetitive inhibitor typically binds to:
(A) The free enzyme
(B) Either the free enzyme or the ES complex
(C) The transition state intermediate only
(D) The enzyme-substrate (ES) complex

2008

65. What are the kinetic consequences of uncompetitive inhibition?
(A) V_{max} remains unchanged, K_m decreases
(B) Both V_{max} and K_m decrease
(C) V_{max} decreases, K_m increases
(D) Both V_{max} and K_m increase

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2006

66. In mixed inhibition, the double-reciprocal plot lines intersect:
(A) On the y-axis
(B) On the x-axis
(C) In the second or third quadrant
(D) They do not intersect (parallel)

2007

67. Non-competitive inhibition is a special case of mixed inhibition where:
(A) The inhibitor binds exclusively to the ES complex
(B) The affinity for the free enzyme and the ES complex is identical
(C) The Michaelis constant is significantly increased
(D) The maximum reaction velocity remains unchanged

2017

68. Which type of reversible inhibitor can be completely overcome by adding a vast excess of substrate?
(A) Competitive
(B) Uncompetitive

(C) Non-competitive
(D) Mixed

2009

69. A diagnostic plot for uncompetitive inhibition on a Lineweaver-Burk graph shows:
(A) Intersecting lines on the y-axis
(B) Parallel lines
(C) Intersecting lines on the x-axis
(D) Non-linear upward curves

2019

70. Allosteric enzymes typically exhibit which type of kinetics?
(A) Hyperbolic
(B) Sigmoidal
(C) Linear
(D) Exponential

2011

71. The Monod-Wyman-Changeux (MWC) model for allosteric regulation postulates that:
(A) All subunits in the oligomer must exist in the same conformational state
(B) Subunits undergo conformational shifts sequentially upon binding events
(C) Negative cooperativity is a common occurrence in all protein systems
(D) The active site and regulatory site are physically identical locations

2013

72. According to the Koshland-Némethy-Filmer (KNF) model of allosterism:
(A) The enzyme maintains strict symmetry in all possible states
(B) T and R states exist in equilibrium prior to any substrate binding
(C) Conformational changes occur sequentially within individual subunits
(D) It exclusively explains positive cooperativity in enzyme systems

2008

73. Feedback inhibition occurs when an enzyme in a metabolic pathway is inhibited by:
(A) Its immediate substrate
(B) An intermediate early in the pathway
(C) A competitive analog from another pathway
(D) The final product of the pathway

2006

74. Zymogen activation is an example of which regulatory mechanism?
(A) Reversible covalent modification
(B) Allosteric regulation
(C) Transcriptional control
(D) Irreversible covalent modification

2016

75. Consider the following statements regarding zymogens:
I. Trypsinogen is a zymogen.
II. Zymogens are irreversibly activated by proteolysis.
III. Zymogens require ATP for activation.
IV. Chymotrypsinogen is synthesized in the pancreas.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) I, II and IV
(C) II, III and IV
(D) I, III and IV

2015

76. Which of the following is the most common form of reversible covalent modification used to regulate enzyme activity?
(A) Methylation
(B) Phosphorylation
(C) Adenylation
(D) Acetylation

2006

77. Protein kinases catalyze the transfer of a phosphate group to specific residues. Which set of amino acids is most commonly phosphorylated?
(A) Serine, Threonine, Tyrosine
(B) Alanine, Glycine, Valine
(C) Cysteine, Methionine, Proline
(D) Histidine, Tryptophan, Phenylalanine

NODIA

2012

78. Isoenzymes (isozymes) are defined as:
(A) Enzymes from different species that perform the same function
(B) Enzymes with similar physical structures but different reactions
(C) Different physical forms of an enzyme catalyzing the same reaction
(D) Inactive precursors of functional enzymes in the cell

2012

79. Lactate dehydrogenase (LDH) exists as a tetramer with how many distinct isoenzyme forms in humans?
(A) 2
(B) 3
(C) 4
(D) 5

2018

80. Pseudoenzymes are structurally related to active enzymes but lack catalytic activity primarily due to:
(A) Evolutionary mutations in key catalytic residues
(B) Exposure to heavy metal poisoning in the cell
(C) Absolute absence of a required prosthetic group
(D) Constant allosteric inhibition by metabolites

2019

81. Enzyme promiscuity refers to an enzyme's ability to:
(A) Catalyze distinct reactions or accept diverse substrates
(B) Bind tightly to a single, highly specific inhibitor
(C) Fold into multiple functional states spontaneously
(D) Function exclusively in unnatural organic solvents

2013

82. Catalytic antibodies, or abzymes, are designed to bind specifically to the:
(A) Native substrate of a target reaction
(B) Final product of a target reaction
(C) Transition state analog of a target reaction
(D) Allosteric site of the target enzyme

2014

83. The primary rationale for developing abzymes is to:
(A) Generate antibodies that destroy pathogens instantly
(B) Create tailored catalysts for reactions lacking natural enzymes
(C) Replace vitamins in human nutrition
(D) Purify industrial enzymes efficiently

2005

84. Which method is NOT commonly used for the physical immobilization of enzymes?
(A) Adsorption
(B) Entrapment within a gel
(C) Covalent cross-linking to a matrix
(D) Simple dilution in aqueous buffer

2014

85. A major advantage of enzyme immobilization in industrial applications is:
(A) It permanently denatures the enzyme
(B) It facilitates continuous processes and enzyme reuse
(C) It increases the enzyme's solubility
(D) It prevents the enzyme from interacting with its substrate

2012

86. In biosensor design, the biological recognition element (e.g., an enzyme) is directly coupled to:
(A) A heat source
(B) A transducer
(C) A solid substrate
(D) A competitive inhibitor

2010

87. A glucose biosensor commonly utilizes which enzyme to monitor blood glucose levels?
(A) Hexokinase
(B) Glycogen phosphorylase
(C) Glucokinase
(D) Glucose oxidase

2005

88. Site-directed mutagenesis is most widely applied in enzyme engineering to:
(A) Alter the DNA to modify amino acids and catalytic properties
(B) Extract native RNA from enzyme-producing host cells
(C) Randomly induce chemical mutations across the genome
(D) Immobilize the enzyme to a solid support matrix

2015

89. Salting out is an enzyme purification technique primarily based on differential:
(A) Molecular weight
(B) Protein solubility at high ionic strength
(C) Net electrical charge
(D) Specific binding affinity

2018

90. Match the items in List I with those in List II:
List I : (Purification Technique)
P. Gel filtration chromatography
Q. Ion-exchange chromatography
R. Affinity chromatography
S. Salting out
List II : (Separation Principle)
1. Specific ligand binding
2. Size and shape
3. Net charge
4. Solubility manipulation
(A) P-2, Q-3, R-1, S-4
(B) P-3, Q-1, R-4, S-2
(C) P-2, Q-1, R-3, S-4
(D) P-1, Q-4, R-2, S-3

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2008

91. In affinity chromatography, an enzyme bound to the column is typically eluted by:
(A) Increasing the temperature
(B) Adding a free ligand that competes for the enzyme
(C) Using a highly non-polar solvent
(D) Decreasing the column pressure

2018

92. Specific activity of an enzyme preparation is defined as:
(A) Total enzyme units divided by total milligrams of protein
(B) Total enzyme units divided by total sample volume
(C) The maximum velocity reached by the total preparation
(D) The purity level estimated by gel electrophoresis

2014

93. During a multi-step enzyme purification process, the specific activity:
(A) Consistently decreases
(B) Remains constant
(C) Increases as purity increases
(D) Fluctuates randomly

2024

94. The fold-purification value in an enzyme isolation protocol is calculated by:
(A) Dividing final specific activity by initial specific activity
(B) Dividing total final units by total initial units
(C) Subtracting final protein content from initial protein content
(D) Multiplying total volume by specific activity

2022

95. Cellulases are widely used in which industrial sector?
(A) Dairy processing
(B) Biofuel production and textile processing
(C) Diagnostic biosensors
(D) High-fructose corn syrup synthesis

2011

96. Amylases have significant agricultural and industrial value because they:
(A) Cleave cellulose fibrils into glucose
(B) Break down lipids in detergents
(C) Degrade structural proteins
(D) Hydrolyze starch into simple sugars

2018

97. Restriction endonucleases are indispensable tools in:
(A) Recombinant DNA technology
(B) Industrial cheese production
(C) Leather tanning
(D) Detergent formulation

2014

98. Which enzyme is a well-known therapeutic agent used in the treatment of acute myocardial infarction?
(A) Urokinase (Tissue plasminogen activator)
(B) Amylase
(C) Taq polymerase
(D) Lipase

2022

99. Which water-soluble vitamin functions as a coenzyme in transamination reactions?
(A) Thiamine (B_1)
(B) Riboflavin (B_2)
(C) Pyridoxine (B_6)
(D) Cobalamin (B_{12})

2012

100. The active coenzyme form of Vitamin B1 (Thiamine) is:
(A) Thiamine pyrophosphate (TPP)
(B) Flavin mononucleotide (FMN)
(C) Nicotinamide adenine dinucleotide (NAD^+)
(D) Pyridoxal phosphate (PLP)

2006

101. Vitamin C (Ascorbic acid) is critically required as a co-substrate in the biosynthesis of:
(A) Collagen
(B) Glycogen
(C) Cholesterols
(D) Purines

2018

102. Which vitamin is a structural component of Coenzyme A (CoA)?
(A) Biotin
(B) Folic acid
(C) Pantothenic acid
(D) Niacin

NODIA

2006

103. Flavin adenine dinucleotide (FAD) is derived from which vitamin?
(A) Vitamin B_1
(B) Vitamin B_2
(C) Vitamin B_3
(D) Vitamin B_6

2015

104. Biotin acts as a prosthetic group for enzymes that catalyze:
(A) Decarboxylation reactions
(B) Transamination reactions
(C) Dehydrogenation reactions
(D) Carboxylation reactions

2024

105. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Vitamin B12 deficiency can lead to pernicious anemia.
Reason (R) : Vitamin B12 is exclusively absorbed in the stomach without the need for intrinsic factor.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2018

106. Folic acid in its active form (Tetrahydrofolate) is essential for:
(A) Cellular respiration
(B) Calcium absorption
(C) Blood coagulation
(D) One-carbon metabolism

2011

107. Which fat-soluble vitamin plays a direct role in the visual cycle?
(A) Vitamin A
(B) Vitamin D
(C) Vitamin E
(D) Vitamin K

2015

108. The active hormonal form of Vitamin D is:
(A) Cholecalciferol
(B) 1,25-dihydroxycholecalciferol (Calcitriol)
(C) Ergocalciferol
(D) Retinoic acid

2008

109. Vitamin E primarily functions biochemically as a:
(A) Coenzyme in carboxylation
(B) Transcriptional regulator
(C) Lipid-soluble antioxidant
(D) Precursor for visual pigments

2025

110. Vitamin K is essential for the post-translational modification of blood clotting factors via the:
(A) Methylation of lysine residues
(B) Hydroxylation of proline residues
(C) Gamma-carboxylation of glutamate residues
(D) Phosphorylation of serine residues

2023

111. Night blindness is a classic clinical manifestation of severe deficiency in:
(A) Vitamin A
(B) Vitamin C
(C) Vitamin D
(D) Vitamin K

2019

112. Scurvy is characterized by bleeding gums and fragile blood vessels due to a deficiency of:
(A) Riboflavin
(B) Vitamin K
(C) Ascorbic acid
(D) Niacin

2025

113. Beriberi is the classical deficiency disease associated with a lack of:
(A) Thiamine
(B) Biotin
(C) Pantothenic acid
(D) Folic acid

2009

114. Rickets in children and osteomalacia in adults are primary clinical manifestations of a deficiency in:
(A) Vitamin A
(B) Vitamin C
(C) Vitamin D
(D) Vitamin E

2013

115. A severe deficiency of Niacin (Vitamin B3) results in which disease?
(A) Pellagra
(B) Megaloblastic anemia
(C) Wernicke-Korsakoff syndrome
(D) Night blindness

2024

116. Peptide hormones fundamentally differ from steroid hormones in that peptide hormones:
(A) Bind to surface receptors and activate second messengers
(B) Enter the target cell to bind nuclear receptors
(C) Are highly hydrophobic and lipid-soluble
(D) Are synthesized from a cholesterol precursor

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2013

117. Which of the following is a classic second messenger activated by many peptide hormones?
(A) Cyclic AMP (cAMP)
(B) Retinoic acid
(C) Cholesterol
(D) Thyroxine

2023

118. Steroid hormones mediate their physiological effects primarily by:
(A) Activating adenylate cyclase in the cell membrane
(B) Opening cell membrane ion channels directly
(C) Binding to receptors acting as transcription factors
(D) Activating receptor tyrosine kinases in the cytoplasm

2019

119. Which second messenger system is associated with the cleavage of phosphatidylinositol 4,5-bisphosphate (PIP_2)?
(A) cAMP and cGMP
(B) Calcium and Calmodulin only
(C) Nitric oxide (NO)
(D) IP_3 and DAG

2014

120. Consider the following combinations regarding hormone classes and signaling:
I. Insulin: Tyrosine kinase receptor
II. Glucagon: GPCR and cAMP
III. Estrogen: Intracellular nuclear receptor
IV. Epinephrine: Intracellular nuclear receptor
V. Cortisol: Steroid hormone
Which of the above combination(s) is/are INCORRECT?
(A) I and II
(B) IV only
(C) III and V
(D) II, IV and V

2016

121. Pituitary gland is directly controlled by releasing and inhibiting hormones from the:
(A) Hypothalamus
(B) Thalamus
(C) Pineal gland
(D) Thyroid gland

2019

122. Which pituitary hormone stimulates the synthesis and secretion of thyroid hormones?
(A) Adrenocorticotropic hormone (ACTH)
(B) Luteinizing hormone (LH)
(C) Thyroid-stimulating hormone (TSH)
(D) Prolactin

2023

123. Gigantism and acromegaly are endocrine disorders caused by the overproduction of:
(A) Thyroid hormone
(B) Cortisol
(C) Insulin
(D) Growth hormone (GH)

2003

124. The biologically active forms of thyroid hormones are:
(A) Tyrosine and Phenylalanine
(B) Triiodothyronine (T_3) and Thyroxine (T_4)
(C) Calcitonin and Parathyroid hormone
(D) Thyroglobulin and TSH

NODIA

2010

125. An autoimmune disease that causes hyperthyroidism by producing antibodies that mimic TSH is known as:
(A) Graves' disease
(B) Hashimoto's thyroiditis
(C) Cushing's syndrome
(D) Addison's disease

2021

126. The adrenal cortex produces all of the following classes of hormones except:
(A) Glucocorticoids
(B) Mineralocorticoids
(C) Catecholamines
(D) Androgens

2002

127. Cortisol, a major glucocorticoid, plays a critical physiological role in:
(A) Decreasing blood glucose levels
(B) Promoting inflammatory responses
(C) Mediating the long-term stress response
(D) Stimulating calcium deposition in bones

2019

128. Addison's disease is clinically characterized by the chronic insufficiency of:
(A) Insulin
(B) Epinephrine
(C) Adrenal cortex hormones (cortisol and aldosterone)
(D) Thyroid hormones

2018

129. The alpha cells of the pancreatic islets secrete which hormone?
(A) Insulin

(A) V_{max} decreases, K_m remains constant
(B) V_{max} decreases, K_m increases
(C) V_{max} remains constant, K_m increases
(D) Both V_{max} and K_m decrease

2012

155. The rate of an enzyme-catalyzed reaction is most heavily dependent on:
(A) The absolute temperature only
(B) The size of the enzyme molecule
(C) The concentration of the enzyme-substrate complex
(D) The concentration of the transition state complex

2018

156. An enzyme with a low K_m for its substrate is most effectively active at:
(A) Low substrate concentrations
(B) Very high substrate concentrations only
(C) High temperatures
(D) Basic pH

2008

157. According to Michaelis-Menten kinetics, if the substrate concentration is equal to K_m, the initial velocity is:
(A) $\frac{1}{2} V_{max}$
(B) V_{max}
(C) $\frac{1}{4} V_{max}$
(D) Zero

2009

158. The unit of turnover number (k_{cat}) is mathematically expressed as:
(A) Reciprocal time (e.g., s^{-1})
(B) Moles per second
(C) Molar concentration per second
(D) Dimensionless

2012

159. The maximum theoretical rate of diffusion-controlled encounters between an enzyme and substrate places an upper limit on:
(A) V_{max}
(B) k_{cat}
(C) Catalytic efficiency ($\frac{k_{cat}}{K_m}$)
(D) The equilibrium constant

2002

160. Which of the following best explains why allosteric enzymes do not strictly obey Michaelis-Menten kinetics?
(A) They consist of multiple subunits exhibiting cooperative binding
(B) They lack active sites
(C) They are purely inorganic catalysts
(D) They bind substrates irreversibly

2015

161. A positive allosteric modulator (activator) generally alters the kinetic curve by:
(A) Shifting it to the left (increasing apparent affinity)
(B) Shifting it to the right (decreasing apparent affinity)
(C) Converting it from sigmoidal to exponential
(D) Lowering the maximum velocity significantly

2017

162. Which regulatory mechanism involves the covalent addition of an adenyl group from ATP to a tyrosine residue?
(A) Adenylylation
(B) Phosphorylation
(C) Uridylylation
(D) ADP-ribosylation

2024

163. Proteolytic cleavage is an irreversible regulatory mechanism prominently utilized in:
(A) Blood coagulation cascades
(B) Glycolysis
(C) Photosynthesis
(D) Lipid biosynthesis

2003

164. The sequential (KNF) model of allosterism accommodates which phenomenon that the symmetry (MWC) model cannot?
(A) Positive cooperativity
(B) Sigmoidal kinetics
(C) Negative cooperativity
(D) Conformational shifts

2022

165. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Pseudoenzymes are highly active catalysts found in specific metabolic bypass pathways.
Reason (R) : They retain the standard fold of active enzymes but lack key catalytic amino acid residues.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.

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(C) Zeatin
(D) 1-Aminocyclopropane-1-carboxylic acid (ACC)

2014

143. Which plant hormone is considered the primary "stress hormone" due to its role in stomatal closure during drought?
(A) Abscisic acid (ABA)
(B) Gibberellin
(C) Ethylene
(D) Cytokinin

2022

144. Abscisic acid counteracts the seed germination-promoting effects of which hormone?
(A) Auxin
(B) Gibberellin
(C) Ethylene
(D) Salicylic acid

2005

145. Salicylic acid plays a critical signaling role in which plant physiological process?
(A) Phototropism
(B) Fruit ripening
(C) Root nodulation
(D) Pathogen defense

2025

146. Brassinosteroids are a class of plant hormones that structurally resemble:
(A) Animal steroid hormones
(B) Animal peptide hormones
(C) Purine bases
(D) Volatile esters

2004

147. Strigolactones have significant agricultural importance because they:
(A) Induce systemic acquired resistance
(B) Delay leaf senescence indefinitely
(C) Stimulate fungal interaction
(D) Promote rapid cell division in the cambium

2013

148. The primary receptor for brassinosteroid signaling in plants is:
(A) TIR1
(B) GID1
(C) BRI1 (a leucine-rich repeat receptor kinase)
(D) ETR1

2016

149. Strigolactones are biosynthesized from which precursor pathway?
(A) Carotenoid pathway
(B) Shikimic acid pathway
(C) Amino acid degradation
(D) Lignin biosynthesis

NODIA

2003

150. Match the items in List I with those in List II:
List I : (Plant Hormone)
P. Ethylene
Q. Abscisic Acid
R. Salicylic Acid
S. Strigolactones
List II : (Physiological Role)
1. Stomatal closure
2. Fruit ripening
3. Mycorrhizal interaction
4. Pathogen defense
(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-4, R-1, S-2
(D) P-2, Q-4, R-1, S-3

2024

151. Which statement best describes a consequence of an enzyme's high specificity?
(A) It discriminates between closely related structural stereoisomers
(B) It catalyzes reactions with multiple disparate substrates randomly
(C) It requires multiple diverse cofactors to function
(D) It functions optimally over a very broad pH range

2008

152. In an endergonic biological reaction, how does enzyme catalysis influence the reaction thermodynamics?
(A) It turns the reaction exergonic
(B) It supplies energy directly from the apoenzyme
(C) It does not change the overall free energy requirement
(D) It inverses the equilibrium constant

2021

153. A competitive inhibitor of an enzyme-catalyzed reaction typically resembles the:
(A) Substrate molecule
(B) Allosteric activator
(C) Enzyme active site
(D) Reaction product

2013

154. What happens to the $V_{\max}$ and K_m of an enzyme when a pure non-competitive inhibitor is introduced?

(D) 50000 units/mg

2002

178. If a purification step results in a 10-fold increase in specific activity, but total activity drops by 50%, this indicates:
(A) The enzyme was denatured completely
(B) The target enzyme was significantly enriched despite some yield loss
(C) A competitive inhibitor was added
(D) The step failed entirely

2017

179. In gel filtration chromatography, molecules are separated strictly based on:
(A) Hydrophobicity
(B) Isoelectric point
(C) Size and molecular weight
(D) Affinity for the matrix ligand

2025

180. Consider the following statements regarding enzyme purification methods:
I. Salting out uses ammonium sulfate.
II. Gel filtration elutes large molecules first.
III. Affinity chromatography relies on specific ligand binding.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I, II and III

2019

181. Which chromatographic method requires the knowledge of an enzyme's specific substrate or competitive inhibitor to design the stationary phase?
(A) Gel filtration chromatography
(B) Ion-exchange chromatography
(C) Hydrophobic interaction chromatography
(D) Affinity chromatography

2002

182. Agricultural application of phytases is primarily focused on:
(A) Improving phosphorus availability from phytic acid in animal feed
(B) Enhancing starch breakdown in seeds
(C) Killing pathogenic fungi on crop leaves
(D) Accelerating fruit ripening

2010

183. Proteases find extensive industrial application in which product formulation?
(A) Detergents for stain removal
(B) Biosensors for glucose
(C) High-fructose corn syrup
(D) Bioethanol production

2021

184. Polymerase Chain Reaction (PCR) crucially relies on the high thermal stability of which enzyme?
(A) EcoRI endonuclease
(B) T4 DNA ligase
(C) Reverse transcriptase
(D) Taq DNA polymerase

2006

185. Therapeutic administration of asparaginase is used in the treatment of:
(A) Acute lymphoblastic leukemia
(B) Myocardial infarction
(C) Type 1 Diabetes
(D) Hemophilia

2013

186. Riboflavin deficiency can result in clinical symptoms collectively known as:
(A) Pellagra
(B) Beriberi
(C) Rickets
(D) Ariboflavinosis

2015

187. Which vitamin is characterized by a complex corrin ring structural motif containing a central cobalt ion?
(A) Vitamin B6
(B) Vitamin B_{12}
(C) Biotin
(D) Folic Acid

2015

188. Vitamin B_{12} absorption in the human terminal ileum strictly requires:
(A) Intrinsic factor secreted by gastric parietal cells
(B) Bile salts from the gallbladder
(C) Direct linkage to dietary lipids
(D) Active transport via vitamin C receptors

2006

189. Pantothenic acid deficiency is exceedingly rare in humans due to its ubiquitous presence in food. However, experimentally induced deficiency leads to:
(A) "Burning feet" syndrome
(B) Complete baldness
(C) Night blindness
(D) Extreme bone brittleness

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(C) A is true but R is false.
(D) A is false but R is true.

2012

166. Isozymes of Lactate Dehydrogenase (LDH) differ principally in their:
(A) Subunit composition (H and M chains)
(B) Prosthetic group requirements
(C) Catalytic reaction (some oxidize, some reduce)
(D) Substrate identity (one uses lactate, another uses pyruvate only)

2024

167. Enzyme promiscuity is evolutionarily significant because it provides:
(A) A starting point for the evolution of new enzymatic functions
(B) Absolute specificity for newly evolved pathways
(C) Complete resistance to competitive inhibition
(D) Protection against covalent modification

2010

168. Which of the following is an example of an inorganic cofactor required for DNA polymerase activity?
(A) Iron (Fe^{2+})
(B) Magnesium (Mg^{2+})
(C) Calcium (Ca^{2+})
(D) Copper (Cu^{2+})

2017

169. Coenzyme A functions prominently in metabolism as a carrier of:
(A) Electrons
(B) Methyl groups
(C) Acyl groups
(D) Phosphoryl groups

2007

170. Nicotinamide adenine dinucleotide (NAD^+) typically accepts how many electrons and protons during a reduction reaction?
(A) 2 electrons, 1 proton
(B) 1 electron, 1 proton
(C) 2 electrons, 2 protons
(D) 1 electron, 2 protons

2014

171. Pyridoxal phosphate (PLP) forms a transient covalent intermediate with amino acid substrates known as a:
(A) Schiff base
(B) Thioester
(C) Phosphoanhydride
(D) Disulfide bond

2003

172. The term "abzyme" is derived from a portmanteau of:
(A) Abnormal enzyme
(B) Antibody enzyme
(C) Absolute zymogen
(D) Abscisic enzyme

2008

173. Immobilized enzymes are heavily utilized in the production of high-fructose corn syrup. Which specific enzyme is typically immobilized for this process?
(A) Alpha-amylase
(B) Glucoamylase
(C) Glucose isomerase
(D) Invertase

2007

174. In biosensor technology, the role of the transducer is to:
(A) Selectively bind the analyte
(B) Convert the signal to electrical form
(C) Keep the enzyme permanently attached
(D) Provide the necessary cofactors

2003

175. Why is site-directed mutagenesis preferred over random mutagenesis in rational enzyme engineering?
(A) It allows for the targeted alteration of specific amino acids based on structural data
(B) It requires no prior knowledge of the enzyme structure
(C) It inherently produces enzymes with higher thermal stability
(D) It avoids the use of recombinant DNA

2024

176. During enzyme purification, which fractional precipitation technique uses high concentrations of ammonium sulfate?
(A) Affinity chromatography
(B) Dialysis
(C) Salting out
(D) Gel filtration

2004

177. A cell extract contains 100 mg of total protein with an overall activity of 500 units. What is the specific activity?
(A) 0.2 units/mg
(B) 5 units/mg
(C) 50 units/mg

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(B) Glucagon
(C) Somatostatin
(D) Pancreatic polypeptide

2011

130. Insulin regulates blood glucose levels primarily by:
(A) Stimulating glycogenolysis in the liver
(B) Promoting gluconeogenesis in the kidney
(C) Facilitating glucose uptake into tissues
(D) Increasing intestinal glucose absorption

2006

131. Type 1 diabetes mellitus is characterized by:
(A) Autoimmune destruction of pancreatic beta cells
(B) Severe cellular insulin resistance
(C) Hypersecretion of insulin
(D) Hyposecretion of glucagon

2021

132. Testosterone and estrogen, the primary gonadal hormones, are synthesized from which precursor?
(A) Amino acids
(B) Cholesterol
(C) Arachidonic acid
(D) Isoprene units

2019

133. Which classical phytohormone is primarily responsible for apical dominance in plants?
(A) Gibberellins
(B) Cytokinins
(C) Auxins
(D) Ethylene

2018

134. Indole-3-acetic acid (IAA) is the most abundant natural form of which plant hormone?
(A) Auxin
(B) Gibberellin
(C) Cytokinin
(D) Abscisic acid

2006

135. Arrange the following events of auxin signaling in the correct sequence:
I. Degradation of Aux/IAA repressor proteins
II. Auxin binds to the TIR1 receptor
III. Activation of ARF transcription factors
IV. Ubiquitination of Aux/IAA by the SCF complex
Which of the following represents the correct sequence?
(A) II, IV, I, III
(B) I, II, IV, III
(C) II, I, IV, III
(D) IV, II, I, III

NODIA

2021

136. Polar transport in plant stems is uniquely characteristic of which hormone?
(A) Cytokinins
(B) Gibberellins
(C) Ethylene
(D) Auxins

2010

137. Which phytohormone is renowned for stimulating dramatic internode elongation and breaking seed dormancy?
(A) Cytokinin
(B) Gibberellin
(C) Abscisic acid
(D) Ethylene

2017

138. The synthesis of gibberellins occurs primarily via the:
(A) Shikimate pathway
(B) Terpenoid (isoprenoid) pathway
(C) Malonate pathway
(D) Phenylpropanoid pathway

2002

139. Cytokinins promote cell division and are chemically derived from:
(A) Adenine
(B) Tryptophan
(C) Methionine
(D) Phenylalanine

2022

140. In plant tissue culture, a high cytokinin to auxin ratio favors the development of:
(A) Roots
(B) Shoots
(C) Undifferentiated callus
(D) Senescent tissues

2002

141. Ethylene is a unique plant hormone because it exists as a:
(A) Complex steroid
(B) Highly water-soluble peptide
(C) Polyamine
(D) Volatile gas

2014

142. The immediate biosynthetic precursor to ethylene in higher plants is:
(A) S-Adenosylmethionine (SAM)
(B) Indole-3-butyric acid (IBA)

2024

190. Folic acid supplementation during early pregnancy is critical to prevent:
(A) Fetal neural tube defects
(B) Gestational diabetes
(C) Maternal hypertension
(D) Congenital heart defects

2018

191. Beta-carotene serves as a primary provitamin precursor for:
(A) Vitamin A
(B) Vitamin D
(C) Vitamin E
(D) Vitamin K

2025

192. The hydroxylation of cholecalciferol to its fully active hormone form, calcitriol, occurs sequentially in which two organs?
(A) Kidneys, then Liver
(B) Skin, then Liver
(C) Liver, then Kidneys
(D) Thyroid, then Kidneys

2001

193. Calcitriol primarily acts to maintain calcium homeostasis by:
(A) Decreasing intestinal calcium absorption
(B) Promoting the rapid excretion of calcium
(C) Sequestering calcium strictly in muscle tissues
(D) Increasing intestinal absorption and renal reabsorption of calcium

2014

194. The predominant naturally occurring and most biologically active form of Vitamin E is:
(A) Gamma-tocotrienol
(B) Beta-carotene
(C) Phylloquinone
(D) Alpha-tocopherol

2023

195. Select the correct order of molecules in the Vitamin D activation pathway:
(A) 7-dehydrocholesterol → Cholecalciferol → 25-hydroxycholecalciferol → Calcitriol
(B) Cholecalciferol → 7-dehydrocholesterol → Calcitriol → 25-hydroxycholecalciferol
(C) 25-hydroxycholecalciferol → 7-dehydrocholesterol → Cholecalciferol → Calcitriol
(D) Calcitriol → Cholecalciferol → 7-dehydrocholesterol → 25-hydroxycholecalciferol

2015

196. The anticoagulant drug Warfarin functions by antagonizing the recycling mechanism of which vitamin?
(A) Vitamin C
(B) Vitamin A
(C) Vitamin E
(D) Vitamin K

2007

197. A hallmark biochemical indicator of Vitamin K deficiency is:
(A) Prolonged prothrombin time (bleeding tendency)
(B) Elevated blood calcium levels
(C) Severe hemolytic anemia
(D) Reduced visual acuity

2016

198. Toxicity (hypervitaminosis) is most likely to occur with which class of vitamins when consumed in extreme excess?
(A) B-complex vitamins
(B) Vitamin C
(C) Fat-soluble vitamins
(D) Both water and fat-soluble vitamins equally

2014

199. Hypothalamic releasing hormones travel to the anterior pituitary via the:
(A) Systemic venous circulation
(B) Lymphatic system
(C) Hypophyseal portal system
(D) Direct neural connections

2019

200. Oxytocin and antidiuretic hormone (ADH) are synthesized in the hypothalamus and released from the:
(A) Anterior pituitary
(B) Posterior pituitary
(C) Adrenal medulla
(D) Pineal gland

2008

201. Which pituitary hormone is characterized by having primarily inhibitory hypothalamic control (via dopamine)?
(A) Prolactin
(B) Growth hormone
(C) Luteinizing hormone
(D) Thyroid-stimulating hormone

2008

202. Goiter, an enlargement of the thyroid gland, can result fundamentally from a lack of dietary:
(A) Iron

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2021

227. Strigolactones initially garnered attention because they stimulate the germination of:
(A) Wheat grains
(B) Parasitic weed seeds like Striga
(C) Deeply dormant forest seeds
(D) Orchid seeds exclusively

2017

228. Shoot branching is antagonistically regulated primarily by which two hormones?
(A) Auxin and Gibberellin
(B) Auxin and Cytokinin
(C) Ethylene and Abscisic acid
(D) Brassinosteroids and Salicylic acid

2018

229. Strigolactones inhibit shoot branching acting downstream of:
(A) Ethylene signaling
(B) Abscisic acid signaling
(C) Gibberellin signaling
(D) Auxin signaling

2008

230. A defining characteristic of a suicide inhibitor (mechanism-based inactivator) is that it:
(A) Binds allosterically to downregulate the enzyme
(B) Is unreactive until acted upon by the enzyme's catalytic mechanism
(C) Only inhibits isoenzymes
(D) Reversibly outcompetes the substrate

2024

231. The temperature at which an enzyme shows maximum catalytic activity is known as the:
(A) Denaturation point
(B) Critical temperature
(C) Optimum temperature
(D) Inactivation point

2002

232. Hexokinase and Glucokinase are classic examples of:
(A) Apoenzymes
(B) Zymogens
(C) Isoenzymes
(D) Abzymes

2007

233. The sigmoidal kinetics of allosteric enzymes reflects:
(A) The requirement for multiple coenzymes
(B) Substrate inhibition at high concentrations
(C) Rapid irreversible denaturation
(D) Cooperative binding among multiple subunits

2001

234. In competitive inhibition, the Lineweaver-Burk plots at various inhibitor concentrations intersect at:
(A) The Y-axis
(B) The X-axis
(C) In the first quadrant
(D) They do not intersect

2005

235. The transition state analog theory suggests that the most effective enzyme inhibitors would structurally resemble the:
(A) Initial substrate
(B) Final product
(C) High-energy molecular configuration attained during catalysis
(D) Enzyme apo-structure

NODIA

2012

236. Penicillin acts as an irreversible inhibitor of which bacterial enzyme?
(A) DNA gyrase
(B) Glycopeptide transpeptidase
(C) RNA polymerase
(D) Beta-lactamase

2018

237. Which technique provides the most precise 3D arrangement of atoms in an enzyme's active site?
(A) Mass spectrometry
(B) X-ray crystallography
(C) Gel electrophoresis
(D) Spectrophotometry

2024

238. Heavy metal poisoning often affects enzymes by acting as:
(A) Competitive inhibitors
(B) Non-competitive inhibitors reacting with sulfhydryl groups
(C) Transcriptional repressors
(D) Covalent cofactors

2006

239. The active site of an enzyme is uniquely characterized by providing a:
(A) Microenvironment that stabilizes the transition state
(B) Highly polar microenvironment only
(C) Flat surface for substrate sliding
(D) Non-specific binding zone

2007

215. Gibberellins promote seed germination by mobilizing stored reserves. They do this by stimulating the aleurone layer to secrete:
(A) Alpha-amylase
(B) Lipase
(C) Pectinase
(D) Cellulase

2002

216. The synthesis of cytokinins is heavily concentrated in the plant's:
(A) Apical shoot meristem
(B) Root tip meristem
(C) Mature senescing leaves
(D) Bark

2025

217. The phenomenon of "Richmond-Lang effect" describes the ability of cytokinins to:
(A) Delay leaf senescence
(B) Hasten fruit ripening
(C) Promote immediate seed dormancy
(D) Induce geotropism

2021

218. The "triple response" of etiolated seedlings is a classic bioassay for:
(A) Ethylene
(B) Auxin
(C) Brassinosteroids
(D) Abscisic acid

2007

219. Ethylene biosynthesis is tightly regulated and uniquely autocatalytic. Which enzyme directly converts ACC to ethylene?
(A) ACC synthase
(B) ACC oxidase
(C) SAM synthetase
(D) Ethylene kinase

2024

220. Abscisic acid (ABA) initiates stomatal closure by causing guard cells to:
(A) Take up massive amounts of potassium (K^+)
(B) Lose potassium (K^+) and consequently water
(C) Thicken their cell walls irreversibly
(D) Undergo rapid mitosis

2023

221. Vivipary (premature seed germination on the parent plant) is often a result of a genetic deficiency in:
(A) Abscisic acid
(B) Gibberellic acid
(C) Ethylene
(D) Cytokinin

2011

222. Salicylic acid biosynthesis in plants occurs predominantly through which metabolic pathway?
(A) Shikimate/Isochorismate pathway
(B) Mevalonate pathway
(C) Non-mevalonate pathway
(D) Glycolytic pathway

2008

223. In systemic acquired resistance (SAR), salicylic acid induces the expression of:
(A) Pathogenesis-related (PR) proteins
(B) Alpha-amylases
(C) ACC oxidases
(D) Chlorophyll synthase

2022

224. Which plant hormone has a chemical structure most analogous to ecdysone (insect molting hormone)?
(A) Jasmonic acid
(B) Brassinosteroid
(C) Strigolactone
(D) Gibberellin

2025

225. Match the items in List I with those in List II:
List I : (Vitamin)
P. Vitamin B1
Q. Vitamin B3
R. Vitamin C
S. Vitamin B5
List II : (Chemical Name)
1. Pantothenic acid
2. Niacin
3. Ascorbic acid
4. Thiamine
(A) P-4, Q-2, R-3, S-1
(B) P-2, Q-4, R-1, S-3
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-3, R-2, S-4

2010

226. Mutants lacking brassinosteroids typically exhibit which prominent phenotype?
(A) Giant, overly branched architecture
(B) Perpetual flowering
(C) Immediate seed germination
(D) Extreme dwarfism and delayed senescence

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(B) Calcium
(C) Iodine
(D) Zinc

2023

203. Parathyroid hormone (PTH) is released in direct response to:
(A) High blood calcium levels
(B) Low blood calcium levels
(C) Low blood glucose levels
(D) High blood sodium levels

2008

204. The adrenal medulla synthesizes and secretes catecholamines, principally epinephrine, as an extension of the:
(A) Parasympathetic nervous system
(B) Somatic motor system
(C) Enteric nervous system
(D) Sympathetic nervous system

2017

205. Aldosterone is a mineralocorticoid that regulates blood pressure by promoting:
(A) Sodium retention and potassium excretion
(B) Sodium excretion and potassium retention
(C) Rapid water loss
(D) Calcium retention

2011

206. Cushing's syndrome is clinically defined by prolonged exposure to high levels of:
(A) Glucagon
(B) Thyroxine
(C) Cortisol
(D) Aldosterone

2006

207. Somatostatin, produced by the delta cells of the pancreas, functions broadly to:
(A) Inhibit the release of both insulin and glucagon
(B) Stimulate the release of both insulin and glucagon
(C) Selectively stimulate insulin only
(D) Mediate targeted glycogenolysis

2005

208. The predominant physiological trigger for glucagon secretion is:
(A) Hypoglycemia
(B) Hyperglycemia
(C) High plasma free fatty acids
(D) Somatostatin release

NODIA

2002

209. Luteinizing hormone (LH) stimulates the Leydig cells in males to produce:
(A) Spermatozoa
(B) Inhibin
(C) Follicle-stimulating hormone
(D) Testosterone

2004

210. Consider the following combinations regarding hormones and their source glands:
I. Calcitonin: Thyroid gland
II. Cortisol: Adrenal Medulla
III. Melatonin: Pineal gland
IV. Glucagon: Pancreas
Which of the above combination(s) is/are INCORRECT?
(A) I and II
(B) II only
(C) III and IV
(D) I, II and IV

2025

211. Estradiol, the major estrogen in humans, exerts its effects primarily by:
(A) Binding to nuclear receptors and altering gene transcription
(B) Binding to membrane G-protein coupled receptors
(C) Acting as an allosteric enzyme modulator
(D) Increasing intracellular cAMP directly

2004

212. In the typical plant root, auxin concentration:
(A) Must be exceedingly high to promote growth
(B) Has absolutely no effect on cell elongation
(C) Promotes branching only
(D) Promotes elongation at lower concentrations than required for stems

2013

213. Auxin induces cell elongation according to the acid growth hypothesis by:
(A) Making the cytoplasm highly acidic
(B) Activating proton pumps that lower cell wall pH
(C) Inhibiting cell wall loosening enzymes
(D) Breaking down the vacuole

2004

214. The "foolish seedling" disease (bakanae) in rice led to the discovery of which phytohormone?
(A) Auxin
(B) Cytokinin
(C) Gibberellin
(D) Ethylene

2016

240. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Phosphorylation of an enzyme always results in its activation.
Reason (R) : Protein kinases add phosphate groups to alter the enzyme's conformation.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

241. A multi-substrate reaction mechanism where one product is released before the second substrate binds must be:
(A) Ordered sequential
(B) Random sequential
(C) Ping-Pong
(D) Allosteric

2024

242. In a Ping-Pong multi-substrate reaction, the enzyme transiently exists in a:
(A) Covalently modified state
(B) Denatured state
(C) Zymogen state
(D) Metal-free state

2004

243. When drawing a Hanes-Woolf plot, the x-axis represents:
(A) $[S]$
(B) v_0
(C) $\frac{[S]}{v_0}$
(D) $\frac{1}{[S]}$

2002

244. The catalytic efficiency of an enzyme is considered "perfect" when it approaches:
(A) 1 $M^{-1}s^{-1}$
(B) 10 to 100 $M^{-1}s^{-1}$
(C) 10^8 to 10^9 $M^{-1}s^{-1}$
(D) 10^{12} to 10^{15} $M^{-1}s^{-1}$

2009

245. Feedback inhibition is biologically advantageous because it:
(A) Prevents the unnecessary overaccumulation of metabolic end-products
(B) Exhausts ATP rapidly
(C) Irreversibly shuts down pathways during stress
(D) Maximizes intermediate buildup

2011

246. What type of mechanism best describes the action of RNA enzymes (ribozymes)?
(A) Catalysis by RNA folding and transition state stabilization
(B) Only structural templating
(C) Random hydrolysis
(D) Solely protein-mediated catalysis

2003

247. A hallmark feature of pseudoenzymes across different kingdoms of life is that they:
(A) Retain significant regulatory or scaffolding roles
(B) Are immediately degraded upon synthesis
(C) Spontaneously mutate back into active enzymes
(D) Always trigger apoptosis

2002

248. Biosensors used for continuous environmental monitoring rely heavily on enzymes because of their:
(A) High specificity and rapid reaction rates
(B) High density
(C) Extreme resistance to boiling
(D) Low cost of raw synthesis

2007

249. Which statement is LEAST accurate regarding the immobilization of enzymes?
(A) It simplifies the separation of product from catalyst
(B) It often enhances the thermal and operational stability of the enzyme
(C) It consistently increases the intrinsic k_{cat} of the enzyme
(D) It is heavily used in the pharmaceutical industry

2022

250. Site-directed mutagenesis is technically facilitated by which molecular biology tool?
(A) Polymerase Chain Reaction (PCR)
(B) Northern blotting
(C) Density gradient centrifugation
(D) Mass spectrometry

2001

251. An enzyme with a turnover number of 1000 s^{-1} catalyzes the conversion of:

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27. (A) The active site is perfectly complementary to the substrate beforehand
The lock-and-key model describes enzyme-substrate interactions by suggesting that the active site possesses a rigid and pre-formed shape that exactly matches the substrate. In this hypothesis, the enzyme and substrate fit together like a key into a specific lock, implying absolute structural complementarity prior to binding. This model emphasizes the high degree of specificity observed in many enzymatic reactions.

28. (B) Affinity labeling
Affinity labeling is a powerful technique used to identify specific amino acids within an enzyme's active site. This method involves using reactive molecules that closely resemble the natural substrate, allowing them to bind specifically to the active site. Once bound, these labels form a stable covalent bond with nearby residues, effectively "tagging" them for further structural or chemical analysis.

29. (C) The active site undergoes a conformational change upon substrate binding
The induced fit model proposes that enzymes are flexible structures rather than rigid templates. According to this theory, the initial binding of a substrate triggers a conformational change in the enzyme, causing the active site to mold itself more precisely around the substrate. This dynamic adjustment optimizes the catalytic interactions and is essential for stabilizing the transition state during the reaction.

30. (C) A is true but R is false.
Affinity labels are indeed valuable tools for mapping enzyme active sites because they mimic the substrate's structure. However, unlike simple competitive inhibitors, these molecules contain reactive functional groups that allow them to form permanent covalent attachments to specific amino acid residues. This covalent bonding is the key feature that distinguishes them from unreactive analogs and enables the identification of catalytic residues.

31. (D) Substitute specific amino acids to assess their catalytic role
Site-directed mutagenesis is a molecular biology technique that allows researchers to precisely alter the genetic code of an enzyme to replace one amino acid with another. By observing the resulting changes in enzymatic activity, scientists can determine the specific contribution of individual residues to substrate binding or the catalytic mechanism. This method is fundamental for understanding the structure-function relationship in proteins.

32. (B) Histidine
Histidine is uniquely suited for catalytic roles because the pK_a of its imidazole side chain is close to the physiological pH of most cells. This property allows the residue to easily donate or accept protons, making it a frequent participant in general acid-base catalysis. Consequently, histidine is often found within the active sites of enzymes, facilitating rapid proton transfers during reactions.

33. (B) The concentration of the enzyme-substrate complex $[ES]$
The steady-state assumption is a fundamental principle in Michaelis-Menten kinetics which posits that during the main course of a reaction, the concentration of the enzyme-substrate complex remains relatively constant. This means the rate at which the complex is formed from free enzyme and substrate is equal to the rate at which it breaks down into products or reverts to reactants.

34. (A) Half of $V_{\max}$
The Michaelis constant is a defining kinetic parameter that represents the specific substrate concentration required for an enzyme to reach half of its maximum possible reaction velocity. It serves as an indicator of how much substrate is needed to effectively occupy the active sites. Mathematically, it is the value on the x-axis that corresponds to the half-maximal point on the velocity curve.

35. (C) Low affinity of the enzyme for its substrate
A high Michaelis constant indicates that a relatively large concentration of substrate is required to achieve half-maximal velocity, which generally reflects a weak interaction between the enzyme and its substrate. In such cases, the enzyme has a low affinity for the molecule, meaning it does not bind or hold onto the substrate as effectively as an enzyme with a low value.

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(B) G-protein coupled receptor
(C) Ligand-gated ion channel
(D) Nuclear transcription factor

2002

264. Thyroid hormones T3 and T4 exert their physiological control primarily by:
(A) Binding to nuclear receptors and regulating gene expression
(B) Rapidly altering membrane potential
(C) Activating cytoplasmic kinases
(D) Releasing calcium from the endoplasmic reticulum

2025

265. What is the fundamental functional difference between the anterior and posterior pituitary?
(A) The posterior is glandular; the anterior is neural
(B) The anterior synthesizes hormones; the posterior only stores them
(C) The anterior relies on positive feedback; the posterior uses negative feedback
(D) The posterior is controlled by the thyroid

2015

266. A major physiological effect of parathyroid hormone (PTH) on bone is to:
(A) Stimulate osteoclast activity to resorb bone and release calcium
(B) Stimulate osteoblast activity to build bone
(C) Increase phosphate deposition
(D) Prevent any mineral turnover

2009

267. Adrenal gland synthesis of cortisol is most immediately stimulated by which hormone?
(A) ACTH
(B) CRH
(C) TSH
(D) Aldosterone

2023

268. Glucocorticoids are widely used pharmacologically for their potent:
(A) Anti-inflammatory and immunosuppressive effects
(B) Hypoglycemic effects
(C) Growth-promoting effects
(D) Diuretic effects

2006

269. The synthesis of melatonin, the hormone regulating circadian rhythms, occurs in the:
(A) Pineal gland
(B) Pituitary gland
(C) Hypothalamus
(D) Adrenal medulla

2003

270. Arrange the steps of classical steroid hormone signaling in the correct sequence:
I. Hormone diffuses across the plasma membrane
II. Alteration of target gene transcription
III. Binding to intracellular receptor
IV. Translocation of hormone-receptor complex to the nucleus
Which of the following represents the correct sequence?
(A) I, III, IV, II
(B) III, I, IV, II
(C) I, IV, III, II
(D) IV, I, III, II

2007

271. In classical plant physiology, "apical dominance" is defined as:
(A) The promotion of root growth by apical leaves
(B) The geotropic response of the primary root
(C) The overriding influence of ethylene on all meristems
(D) The inhibition of lateral buds by auxin produced in the shoot apex

NODIA

2017

272. Auxin is primarily biosynthesized in the plant's:
(A) Shoot apical meristems and young leaves
(B) Mature roots
(C) Old, senescing leaves
(D) Xylem vessels

2024

273. Gibberellic acid (GA) signaling relies on the degradation of which repressor protein family?
(A) DELLA
(B) Aux/IAA
(C) JAZ
(D) MYC2

2025

274. The two-component signaling system, originally found in bacteria, is the primary signal transduction mechanism for which plant hormone?
(A) Cytokinin
(B) Auxin
(C) Gibberellin
(D) Abscisic acid

9. (B) Oxidoreductases
Dehydrogenases are primary members of the first class of enzymes, which facilitate the transfer of electrons or hydrogen atoms between molecules. These proteins play a central role in cellular respiration and energy production by managing oxidation-reduction reactions. By moving electrons from a donor substrate to an electron acceptor like nicotinamide adenine dinucleotide, they drive the fundamental energetic processes of life.

10. (B) Strictly require nucleoside triphosphates like ATP
The distinction between synthetases and synthases lies in their energetic requirements for bond formation. Synthetases are members of the ligase class and specifically catalyze the joining of two molecules using the energy derived from the hydrolysis of nucleoside triphosphates. In contrast, synthases are typically lyases or transferases that facilitate synthesis reactions without a direct requirement for high-energy phosphate bond cleavage.

11. (A) $\Delta G^{\circ} = - RT \ln K_{eq}$
The standard free energy change of a biochemical reaction is fundamentally linked to its equilibrium constant through a logarithmic relationship. This mathematical expression incorporates the universal gas constant and the absolute temperature to quantify the energy available to do work under standard conditions. A negative value indicates a spontaneous reaction, reflecting the inherent thermodynamic stability and directionality of metabolic processes.

12. (C) Lowering the activation energy
Enzymes act as biological catalysts that significantly increase the rate of chemical reactions by providing an alternative pathway with a reduced energetic barrier. By stabilizing the transition state and lowering the activation energy required for the reaction to proceed, enzymes allow substrates to reach the product state more rapidly. Importantly, they achieve this acceleration without altering the overall reaction thermodynamics.

13. (D) A transient species with the highest free energy
The transition state represents a brief and unstable configuration of atoms that exists at the peak of the energy barrier during a chemical transformation. It is characterized by having the highest free energy along the reaction coordinate, marking the point where old bonds are breaking and new ones are forming. Enzymes function primarily by binding and stabilizing this specific high-energy state.

14. (C) Presence of a catalyst
The standard free energy change is a state function that depends solely on the chemical nature of the reactants and products, as well as environmental factors like temperature and pressure. While catalysts such as enzymes dramatically accelerate the speed at which a reaction reaches equilibrium, they do not influence the final equilibrium position or the overall thermodynamic difference between the states.

15. (B) P-3, Q-2, R-4, S-1
Enthalpy represents the total heat content of a system, while entropy serves as a measure of the disorder or randomness present. Free energy identifies the portion of energy available to perform useful work during a process. In contrast, activation energy is the specific amount of energy that molecules must acquire to reach the transition state and initiate a chemical reaction.

16. (D) Lower than the reactants
In an exergonic reaction, the total free energy contained within the products is less than the energy initially present in the reactants. This difference results in a net release of energy to the surroundings, making the process thermodynamically favorable and spontaneous. Enzymes facilitate these reactions by lowering the kinetic barriers, though they do not change the final energy states involved.

17. (A) The transition state
Binding energy is the free energy released when an enzyme forms multiple weak interactions with its substrate. According to modern catalytic theory, these interactions are optimized and reach their maximum strength when the substrate is in the transition state. This release of energy provides the driving force needed to lower the activation barrier, thereby accelerating the overall rate of the reaction.

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(C) A is true but R is false.
(D) A is false but R is true.

2006

286. Thermophilic enzymes (extremozymes) are highly valued in industry because they:
(A) Retain functionality and stability at elevated processing temperatures
(B) Denature quickly and allow for easy product recovery
(C) Require no cofactors whatsoever
(D) Function exclusively at freezing temperatures

2013

287. Which biochemical parameter determines the catalytic perfection of an enzyme?
(A) A $\frac{k_{cat}}{K_m}$ ratio approaching the diffusion-controlled limit
(B) A very high Km value
(C) A low k_{cat} value
(D) The complete absence of feedback inhibition

2015

288. Allosteric modulators bind to an enzyme's:
(A) Active site only
(B) Transition state only
(C) Regulatory site distinct from the active site
(D) Prosthetic group strictly

2024

289. Which structural level of a protein is most directly responsible for the specific functional folding of an enzyme's active site?
(A) Tertiary structure
(B) Primary structure
(C) Secondary structure
(D) Subunit assembly solely

2012

290. Consider the following statements regarding plant bioregulators:
I. Salicylic acid mediates systemic acquired resistance.
II. Brassinosteroids are synthesized from carotenoids.
III. Strigolactones suppress shoot branching.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I, II and III

2008

291. What is the defining trait of an apoenzyme compared to a holoenzyme?
(A) It is devoid of its necessary non-protein cofactor
(B) It is functionally fully active
(C) It is heavily glycosylated
(D) It only acts on synthetic substrates

2023

292. During non-competitive inhibition, the intercept on the X-axis of a Lineweaver-Burk plot:
(A) Remains unchanged
(B) Moves closer to zero
(C) Moves further from zero
(D) Becomes positive

2024

293. The primary reason organic solvents generally denature enzymes is because they:
(A) Disrupt the crucial hydrophobic interactions required for the 3D structure
(B) Compete with substrates for the active site
(C) Specifically break peptide bonds
(D) Remove all heavy metals

2012

294. Identify the classic symptom of scurvy related to defective collagen biosynthesis.
(A) Bleeding gums and poor wound healing
(B) Excessive bone calcification
(C) Severe muscle hypertrophy
(D) Uncontrollable nerve firing

2005

295. Consider the following combinations regarding endocrinology:
I. Glucagon: Decreases blood glucose
II. Insulin: Increases lipogenesis
III. Cortisol: Increases gluconeogenesis
IV. Aldosterone: Retains sodium
Which of the above combination(s) is/are INCORRECT?
(A) I only
(B) II and IV
(C) III only
(D) I and III

NODIA

2003

296. The principal biological role of cytochromes functioning as oxidoreductases is:
(A) Electron transport mediated by a reversible iron redox state
(B) Cleaving DNA sequences
(C) Hydration of carbon dioxide
(D) Transferring phosphate groups from ATP

2009

297. What kinetic effect does an uncompetitive inhibitor have on a Lineweaver-Burk plot?

(A) 1000 substrate molecules per second per enzyme active site
(B) 1000 moles of substrate per minute
(C) 1000 substrate molecules before denaturing
(D) 1000 grams of product per liter

2004

252. The term "salting out" primarily relies on the physical phenomenon of:
(A) Competition for solvation water between the added salt and the protein
(B) Decreasing the dielectric constant of the medium
(C) Increasing the covalent bonding between proteins
(D) Denaturation by high acidity

2004

253. In an enzyme assay, a continuous monitoring method relies on:
(A) Measuring a product's appearance (e.g., absorbance change) in real-time
(B) Stopping the reaction at discrete time points
(C) Precipitating the enzyme to measure mass
(D) Using radioactive substrates exclusively

2022

254. A commonly used colorimetric assay for quantifying total protein during enzyme purification is the:
(A) Bradford assay
(B) Sanger method
(C) Edman degradation
(D) Southern blot

2025

255. Consider the following statements regarding water-soluble vitamins:
I. Biotin requires an intrinsic factor.
II. Vitamin C acts as an antioxidant.
III. Folic acid is needed for DNA synthesis.
IV. Pyridoxine is vital for transaminases.
V. Thiamine deficiency causes Beriberi.
Which of the above statement(s) is/are correct?
(A) I only
(B) II, III, IV, and V
(C) IV and V
(D) I and IV

2015

256. Which fat-soluble vitamin is derived largely from the diet but can also be synthesized by gut microbiota?
(A) Vitamin K
(B) Vitamin A
(C) Vitamin D
(D) Vitamin E

2009

257. The primary biochemical consequence of severe Vitamin C deficiency is the:
(A) Cessation of fatty acid oxidation
(B) Failure to absorb iron in the intestine entirely
(C) Inability to hydroxylate proline and lysine in collagen
(D) Immediate destruction of red blood cells

2005

258. Pellagra, characterized by dermatitis, diarrhea, and dementia, results fundamentally from a lack of the precursor needed to synthesize:
(A) NAD+/NADP+
(B) FAD
(C) Coenzyme A
(D) TPP

2002

259. Wernicke-Korsakoff syndrome is a severe neurological manifestation primarily seen in chronic alcoholics suffering from a deficiency of:
(A) Thiamine
(B) Riboflavin
(C) Cobalamin
(D) Folic acid

2009

260. Which vitamin must undergo a photochemical reaction in the skin for its endogenous synthesis?
(A) Vitamin D
(B) Vitamin A
(C) Vitamin C
(D) Vitamin E

2013

261. The visual pigment rhodopsin is formed by the binding of opsin to:
(A) 11-cis-retinal
(B) All-trans-retinal
(C) Retinoic acid
(D) Beta-carotene

2006

262. In the signal transduction of glucagon, the direct target of activated G-alpha protein is:
(A) Adenylate cyclase
(B) Protein kinase C
(C) Phospholipase C
(D) Tyrosine kinase

2016

263. When activated, the insulin receptor fundamentally acts as a:
(A) Receptor tyrosine kinase

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ANSWERS

1. (A) Transferases
Transferases represent the second major class within the enzyme classification scheme established by the International Union of Biochemistry and Molecular Biology. These specific proteins are responsible for facilitating the movement of various chemical functional groups from a donor molecule to an acceptor. This essential process enables the redistribution of atoms within metabolic pathways without requiring water for bond cleavage.

2. (C) The third digit denotes the specific substrate
The Enzyme Commission numbering system provides a systematic hierarchy for identification where the first digit signifies the major class and the second denotes the subclass. However, the third digit identifies the sub-subclass, which often refers to the specific type of acceptor or chemical group involved in the reaction. The fourth digit represents the unique serial number of the enzyme.

3. (D) Class 6
Ligases are categorized as Class 6 according to the standard biochemical nomenclature system. These enzymes facilitate the joining of two large molecules by creating new chemical bonds, such as carbon-carbon or carbon-sulfur linkages. This energy-dependent process is typically coupled with the hydrolysis of adenosine triphosphate or similar nucleoside triphosphates to drive the unfavorable synthesis of complex biological structures.

4. (D) Intramolecular rearrangement of atoms
Isomerases belong to the fifth major class of enzymes and function by catalyzing the conversion of a molecule into its structural or geometric isomer. This process involves the internal movement of atoms or functional groups within a single molecule. By facilitating these intramolecular rearrangements, isomerases play a crucial role in preparing metabolites for subsequent steps in various complex biochemical pathways.

5. (B) The precise chemical reaction catalyzed
In biochemical nomenclature, a systematic name is designed to provide an unambiguous description of the exact chemical transformation facilitated by the enzyme. Unlike common names, which may be vague or historical, the systematic name explicitly identifies the substrates and the nature of the reaction. This standardized approach ensures consistency and clarity when researchers communicate about specific catalytic activities in biology.

6. (C) Transferases
Transaminases are vital enzymes that facilitate the movement of an amino group from an amino acid to a keto acid. Because their primary function involves the relocation of a specific functional group between distinct molecules, they are categorized under the transferase class. This group-transfer activity is essential for nitrogen metabolism, allowing the body to synthesize and degrade various amino acids.

7. (C) EC 3
Peptidases are enzymes that catalyze the cleavage of peptide bonds through a hydrolytic mechanism involving the addition of a water molecule. According to the Enzyme Commission classification system, all enzymes that facilitate the breaking of chemical bonds using water are grouped into Class 3, known as hydrolases. This group includes a wide variety of digestive enzymes essential for protein degradation.

8. (A) They require ATP hydrolysis for their primary action
Lyases are characterized by their ability to cleave various chemical bonds through mechanisms other than hydrolysis or oxidation, often resulting in the formation of double bonds or the addition of groups to existing double bonds. Unlike ligases, which require the consumption of energy from adenosine triphosphate to join molecules, lyases operate independently of nucleoside triphosphate hydrolysis for their primary bond-breaking activities.

NODIA

2006

275. Climacteric fruit ripening is strictly dependent on a massive surge of which hormone?
(A) Auxin
(B) Ethylene
(C) Abscisic acid
(D) Salicylic acid

2023

276. Abscisic acid mediates the adaptation of plants to severe water deficit primarily by:
(A) Inducing root shedding
(B) Stimulating rapid stomatal closure
(C) Promoting massive stem elongation
(D) Blocking all photosynthesis permanently

2024

277. The "hypersensitive response" (HR) during plant-pathogen interactions is tightly linked to the localized production of:
(A) Salicylic acid and reactive oxygen species
(B) Gibberellins
(C) Strigolactones
(D) Auxins

2019

278. Which phytohormone class is fundamentally essential for normal photomorphogenesis, skotomorphogenesis, and cell expansion in plants?
(A) Brassinosteroids
(B) Strigolactones
(C) Salicylic acid
(D) Jasmonic acid

2006

279. Mycorrhizal fungi detect the presence of host plant roots by sensing exuded:
(A) Strigolactones
(B) Auxins
(C) Ethylene
(D) Cytokinins

2007

280. Match the items in List I with those in List II:
List I : (Plant Bioregulator)
P. Salicylic acid
Q. Brassinosteroids
R. Strigolactones
S. Jasmonic acid
List II : (Chemical Category)
1. Lipid-derived cyclopentanone
2. Phenolic compound
3. Steroid hormone
4. Carotenoid-derived lactone
(A) P-2, Q-3, R-4, S-1
(B) P-3, Q-2, R-1, S-4
(C) P-4, Q-1, R-3, S-2
(D) P-2, Q-4, R-1, S-3

2018

281. The specific activity of an enzyme preparation is the best direct indicator of the preparation's:
(A) Purity
(B) Total yield
(C) Molecular weight
(D) Total volume

2013

282. In enzyme kinetics, a reaction that is directly proportional to the substrate concentration is categorized as:
(A) Zero-order
(B) First-order
(C) Second-order
(D) Mixed-order

2013

283. The steady-state assumption made by Briggs and Haldane posits that:
(A) The rate of ES complex formation equals the rate of its breakdown
(B) The enzyme is instantly denatured
(C) Substrate concentration changes rapidly at the end of the reaction
(D) Product concentration must remain strictly zero

2008

284. Which statement accurately differentiates uncompetitive from non-competitive inhibition?
(A) Uncompetitive only binds free enzyme; non-competitive binds both
(B) Uncompetitive lowers both $V_{\max}$ and K_m; non-competitive lowers only $V_{\max}$
(C) Uncompetitive increases K_m; non-competitive decreases K_m
(D) There is no kinetic difference between them

2022

285. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Plant roots exhibit positive gravitropism mediated by auxin redistribution.
Reason (R) : High auxin concentrations on the lower side of the root inhibit cell elongation, causing the root to bend downward.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.

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18. (C) It dictates the equilibrium constant of the reaction
Activation energy acts as a kinetic barrier that determines how fast a reaction occurs by limiting the number of molecules capable of reaching the transition state. While temperature can influence this rate, the activation energy itself does not determine the final equilibrium constant. Instead, the equilibrium constant is dictated by the thermodynamic difference in free energy between the reactants and products.

19. (D) The inactive protein component of an enzyme
An apoenzyme refers to the purely proteinaceous part of a complex enzyme that requires a non-protein cofactor to become functional. In its isolated form, the apoenzyme lacks the necessary chemical groups or structural features provided by the cofactor and is therefore catalytically inactive. Only upon binding its specific cofactor does the protein transform into its active, functionally competent structural state.

20. (B) Holoenzyme
A holoenzyme is defined as the complete and catalytically active form of an enzyme, consisting of the protein component combined with its necessary cofactors. These cofactors can be metal ions or complex organic molecules like coenzymes. The formation of this complex is essential for the enzyme to perform its biological function, as the cofactor often participates directly in the catalytic mechanism.

21. (B) Magnesium (Mg^{2+})
Inorganic metallic cofactors are essential non-protein components that assist enzymes in catalysis, often by stabilizing negative charges or participating in redox reactions. Magnesium ions serve as a prominent example, frequently acting as cofactors for enzymes involved in phosphate group transfers, such as kinases. Unlike organic coenzymes like flavin adenine dinucleotide, these metal ions are simple, elemental species required for activity.

22. (A) Prosthetic group
A prosthetic group is a type of coenzyme or cofactor that remains tightly or even covalently attached to the protein structure of an enzyme throughout the entire catalytic cycle. This permanent association distinguishes them from cosubstrates, which bind and release during the reaction. Prosthetic groups are vital for maintaining the enzyme's active site architecture and facilitating the continuous transfer of chemical groups.

23. (C) Cosubstrate
Cosubstrates are organic cofactors that interact with enzymes only temporarily during the catalytic process. They function as transient carriers of specific atoms or functional groups and dissociate from the enzyme after the reaction is complete to be regenerated elsewhere. This distinguishes them from prosthetic groups, which remain permanently bound. Common examples include nicotinamide adenine dinucleotide and coenzyme A in metabolic pathways.

24. (D) Carbonic anhydrase
Zinc is a critical inorganic cofactor for several enzymes, most notably carbonic anhydrase, where it plays a direct role in the catalytic mechanism. In this enzyme, the zinc ion coordinates with water molecules to facilitate the rapid conversion of carbon dioxide and water into bicarbonate. This interaction is essential for maintaining acid-base balance and facilitating gas transport within the human body.

25. (C) Prosthetic group - Tightly bound coenzyme
Enzymes are often composed of a protein part and a non-protein part that work together to achieve catalysis. A prosthetic group is specifically defined as a coenzyme that is bound very tightly or covalently to the apoenzyme, ensuring its constant presence at the active site. This permanent linkage is a key structural feature for enzymes requiring continuous assistance from these complex molecules.

26. (C) It binds substrates through multiple weak interactions
The active site is a specialized pocket within an enzyme where substrate binding and catalysis occur. This region typically utilizes a combination of hydrogen bonds, ionic interactions, and van der Waals forces to hold the substrate in the correct orientation. These multiple weak interactions provide both the specificity required to distinguish between different molecules and the energy needed to stabilize the transition state.

NODIA

(A) Shifts the line parallel to the uninhibited line
(B) Rotates the line around the x-intercept
(C) Rotates the line around the y-intercept
(D) Curves the line upwards

2024

298. In animal cell signaling, which hormone utilizes a receptor that intrinsically possesses tyrosine kinase activity?
(A) Insulin
(B) Epinephrine
(C) Glucagon
(D) Cortisol

2007

299. The "lock and key" hypothesis fundamentally failed to explain which crucial aspect of enzymology?
(A) Substrate specificity
(B) Enzyme saturation
(C) Transition state stabilization
(D) The existence of cofactors

2015

300. Consider the following statements regarding newer plant bioregulators:
I. Brassinosteroids bind to a membrane-localized receptor kinase (BRI1).
II. Strigolactones are chemically categorized as carotenoid-derived lactones.
III. Salicylic acid causes the localized accumulation of pathogenesis-related proteins.
IV. Strigolactones inhibit mycorrhizal colonization.
V. Brassinosteroid mutants are typically dwarf.
Which of the above statement(s) is/are correct?
(A) I, II, III and V
(B) I, III, IV and V
(C) II, III, IV and V
(D) I, II, IV and V

****

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36. (D) k_{cat}
The turnover number, denoted as k_{cat}, represents the maximum number of substrate molecules that a single enzyme active site can convert into product per unit of time when the enzyme is fully saturated. This parameter provides a direct measure of the intrinsic catalytic speed of the enzyme. It is calculated by dividing the maximum velocity by the total concentration of enzyme active sites.

37. (C) $\frac{k_{cat}}{K_m}$
Catalytic efficiency is a vital kinetic parameter determined by calculating the ratio of the turnover number to the Michaelis constant. This value reflects how effectively an enzyme captures and converts substrate at low concentrations, where the enzyme is not saturated. It allows for a direct comparison of the effectiveness of different enzymes or the preference of one enzyme for various substrates.

38. (B) The diffusion rate of the substrate
When an enzyme reaches the state of catalytic perfection, its reaction rate is so fast that it is limited only by how quickly the substrate can move through the solution to reach the active site. At this stage, the catalytic efficiency approaches the diffusion-controlled limit, typically around ten to the eighth or ninth power per molar per second, representing the ultimate physical speed.

39. (D) $V_{\max}$
In enzymatic reactions where the concentration of substrate far exceeds the Michaelis constant, virtually all of the enzyme molecules are occupied by substrate. Under these saturating conditions, the reaction velocity becomes independent of the substrate concentration and reaches its theoretical maximum, known as $V_{\max}$. This represents the point where the enzyme is working at its full catalytic capacity in the system.

40. (A) Lineweaver-Burk plot
The Lineweaver-Burk plot is a common linear transformation of the Michaelis-Menten equation that uses double-reciprocal values to analyze enzyme kinetics. By plotting the reciprocal of the initial velocity against the reciprocal of the substrate concentration, researchers can generate a straight line. This graphical approach simplifies the determination of key kinetic parameters like the maximum velocity and the Michaelis constant from experimental data.

41. (C) $\frac{1}{V_{\max}}$
In the double-reciprocal Lineweaver-Burk plot, the point where the straight line crosses the vertical y-axis provides the value for the reciprocal of the maximum velocity. By calculating the inverse of this intercept, researchers can accurately determine the $V_{\max}$ of the enzyme-catalyzed reaction. This graphical feature is a fundamental tool for analyzing the effects of different types of inhibitors on enzyme activity.

42. (A) $-\frac{1}{K_m}$
On a Lineweaver-Burk plot, the intersection of the data line with the horizontal x-axis represents the negative reciprocal of the Michaelis constant. This specific intercept allows for the direct calculation of the enzyme's affinity for its substrate from experimental kinetic data. This graphical representation is highly useful for distinguishing between different modes of inhibition based on how the intercept changes.

43. (D) Hanes-Woolf plot
The Hanes-Woolf plot is considered more statistically robust than the Lineweaver-Burk plot because it minimizes the impact of experimental errors typically found at low substrate concentrations. By plotting the ratio of substrate concentration to velocity against the substrate concentration, it yields a linear relationship where data points are more evenly spaced. This leads to more accurate estimations of maximum velocity and the Michaelis constant.

44. (B) v_0 versus $\frac{v_0}{[S]}$
The Eadie-Hofstee plot is a linear transformation used in enzyme kinetics that graphs the initial reaction velocity against the ratio of velocity to substrate concentration. This specific arrangement results in a straight line where the y-intercept represents the maximum velocity and the negative slope corresponds to the Michaelis constant. This plot is often used as an alternative to double-reciprocal graphs for visualizing kinetic data.

45. (C) IV only
In enzyme kinetic analysis, different linear transformations yield specific graphical features.

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hormone-receptor complex then acts directly as a transcription factor, binding to specific DNA sequences to regulate the expression of target genes and coordinate long-term physiological changes.

119. (D) IP3 and DAG
Some peptide hormones activate a signaling pathway that involves the cleavage of a specific membrane phospholipid by the enzyme phospholipase C. This reaction produces two distinct second messengers: inositol trisphosphate and diacylglycerol. Inositol trisphosphate triggers the release of calcium ions from internal stores, while diacylglycerol stays in the membrane to activate protein kinase C, together mediating complex cellular responses.

120. (B) IV only
While most steroid and thyroid hormones utilize intracellular receptors to regulate gene expression, epinephrine is a catecholamine that functions differently. Epinephrine is water-soluble and acts by binding to G-protein coupled receptors on the surface of cells, rather than entering the cell to interact with nuclear receptors. Therefore, the claim that it utilizes an intracellular nuclear receptor is biochemically incorrect.

121. (A) Hypothalamus
The hypothalamus serves as the primary control center for the endocrine system, coordinating the activity of the pituitary gland. It produces several releasing and inhibiting hormones that travel through a specialized portal blood system to reach the anterior pituitary. By regulating the secretion of pituitary hormones, the hypothalamus indirectly controls various physiological processes, including growth, metabolism, and the stress response.

122. (C) Thyroid-stimulating hormone (TSH)
Thyroid-stimulating hormone is a glycoprotein produced by the anterior pituitary gland that specifically targets the thyroid gland. Its primary role is to stimulate the thyroid to produce and secrete the hormones thyroxine and triiodothyronine. This process is tightly regulated by a negative feedback loop involving the levels of thyroid hormones in the blood and the secretion of thyrotropin-releasing hormone.

123. (D) Growth hormone (GH)
Gigantism and acromegaly are endocrine disorders resulting from the excessive secretion of growth hormone, typically due to a pituitary tumor. If the overproduction occurs during childhood before the bone plates have fused, it leads to gigantism and extreme height. In adults, the same excess causes acromegaly, characterized by the abnormal enlargement of the hands, feet, and facial features.

124. (B) Triiodothyronine (T_3) and Thyroxine (T_4)
The thyroid gland produces two primary iodine-containing hormones, known as triiodothyronine and thyroxine. These molecules are essential for regulating the basal metabolic rate, body temperature, and the growth and development of many tissues. While thyroxine is produced in larger quantities, triiodothyronine is the more biologically active form, often created by the conversion of thyroxine in peripheral tissues like the liver.

NODIA

125. (A) Graves' disease
Graves' disease is a specific autoimmune condition that is the most common cause of hyperthyroidism. In this disorder, the immune system produces abnormal antibodies, known as thyroid-stimulating immunoglobulins, which bind to and activate the TSH receptors on thyroid cells. This mimics the action of the pituitary hormone, causing the gland to overproduce thyroid hormones regardless of the body's actual needs.

126. (C) Catecholamines
The adrenal gland is divided into two distinct regions with different functions. The outer layer, or cortex, is responsible for producing steroid hormones such as glucocorticoids, mineralocorticoids, and androgens. In contrast, the inner region, known as the adrenal medulla, synthesizes catecholamines like epinephrine and norepinephrine. Therefore, catecholamines are not products of the adrenal cortex but are instead secreted during acute stress.

127. (C) Mediating the long-term stress response
Cortisol is the primary glucocorticoid produced by the adrenal cortex and plays a vital role in helping the body respond to prolonged stress. It acts by increasing blood glucose levels through gluconeogenesis, suppressing the immune system, and altering the metabolism of fats and proteins.

functional groups within the enzyme's active site, such as the side chains of histidine or aspartate. This differs from specific catalysis, which relies solely on hydronium or hydroxide ions from water. By providing these proton donors and acceptors, the enzyme can stabilize charged intermediates and accelerate the reaction.

55. (A) Nucleophilic
Covalent catalysis involves the formation of a temporary chemical bond between the enzyme and the substrate during the reaction. This process typically begins when a nucleophilic functional group on the enzyme, such as the hydroxyl group of serine or the thiol group of cysteine, attacks an electrophilic center on the substrate. This intermediate state is later broken down to release the final product.

56. (D) Increasing the hydration shell of the substrate
Metal ions participate in enzyme catalysis through several mechanisms, including orienting substrates for reaction, stabilizing negative charges on intermediates, and facilitating oxidation-reduction processes. However, they do not typically function by increasing the hydration shell around a substrate. In fact, many enzymes work by excluding water from the active site to prevent unwanted side reactions or to enhance the electrostatic environment.

57. (B) Lowering the entropy of the substrates
The proximity and orientation effect significantly enhances reaction rates by bringing substrates together in the active site and aligning them perfectly for catalysis. This process effectively converts a translational and rotational search into a more ordered state, which greatly reduces the entropy of the substrates. By restricting their movement, the enzyme ensures that collisions are frequent and productive for reaching the transition state.

58. (C) Serine, Histidine, Asparate
Chymotrypsin is a well-studied protease that utilizes a specific arrangement of three amino acids, known as the catalytic triad, to cleave peptide bonds. This triad consists of serine, which acts as the primary nucleophile, histidine, which serves as a general base and acid, and aspartate, which stabilizes the system. Together, these residues coordinate their actions to achieve efficient and rapid protein degradation.

59. (D) It stabilizes the positive charge on histidine
Within the catalytic triad of chymotrypsin, the aspartate residue plays a crucial supporting role by forming a hydrogen bond with the nearby histidine. This interaction helps to properly orient the histidine and stabilizes the positive charge that develops on it during the reaction. By doing so, aspartate makes histidine a more effective base, which in turn enhances the nucleophilicity of the serine residue.

60. (B) III, II, I, IV
Covalent catalysis follows a logical sequence starting with a nucleophilic attack by a functional group in the enzyme's active site on the substrate. This attack leads to the formation of a stable, yet transient, covalent intermediate between the enzyme and substrate. Subsequently, this intermediate is broken down to release the reaction product, and finally, the free enzyme is regenerated for another cycle.

61. (B) Free enzyme at the active site
Competitive inhibition occurs when a molecule that structurally resembles the substrate binds directly to the active site of the free enzyme. Because the inhibitor and substrate compete for the same physical location, the binding of one prevents the binding of the other. This competition can be overcome by increasing the substrate concentration, which effectively displaces the inhibitor from the active site of the enzyme.

62. (A) Increases
In the presence of a competitive inhibitor, a higher concentration of substrate is required to achieve the same reaction velocity as in the uninhibited state. This results in an increase in the apparent Michaelis constant, reflecting the reduced likelihood of the substrate binding to the enzyme. However, because the inhibitor can be displaced by excess substrate, the enzyme's maximum velocity remains completely unchanged.

63. (C) It remains unchanged
Competitive inhibition is characterized by the fact that the inhibitor and substrate vie for the same active site on the enzyme. If the concentration of the substrate is increased to sufficiently high levels, it will eventually outcompete the inhibitor and occupy all available active sites. Consequently, the maximum reaction velocity is

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role in the evolution of new metabolic pathways and biological functions.

82. (C) Transition state analog of a target reaction
Catalytic antibodies are developed by immunizing an animal with a stable molecule that mimics the high-energy transition state of a specific chemical reaction. Because the resulting antibodies are designed to bind these transition state analogs with high affinity, they also stabilize the actual transition state of the reaction. This stabilization effectively lowers the activation energy, allowing the antibody to function as a tailored enzyme.

83. (B) Create tailored catalysts for reactions lacking natural enzymes
The primary goal of developing catalytic antibodies is to expand the toolkit of available catalysts beyond those found in nature. By leveraging the immense diversity and specificity of the immune system, researchers can design abzymes for unique chemical transformations that do not have a known natural enzyme. This technology has significant potential for applications in synthetic chemistry, biotechnology, and personalized medicine.

84. (D) Simple dilution in aqueous buffer
Enzyme immobilization involves physically or chemically restricting an enzyme's movement to a specific region or support. Common techniques include adsorption onto a surface, entrapment within a gel matrix, or covalent cross-linking. In contrast, simple dilution in an aqueous buffer keeps the enzyme in a free, soluble state, which is the opposite of immobilization and does not provide the benefits of catalyst recovery.

85. (B) It facilitates continuous processes and enzyme reuse
Immobilizing enzymes onto solid supports offers significant advantages for industrial applications by allowing the catalyst to be easily separated from the product stream. This enables the continuous operation of bioreactors and the reuse of expensive enzymes over multiple cycles, greatly reducing overall production costs. Additionally, immobilization often increases the stability of enzymes against harsh industrial conditions like high temperatures or organic solvents.

86. (B) A transducer
A biosensor is an analytical device that combines a biological recognition element, such as a specific enzyme, with a physical transducer. The enzyme interacts selectively with the target analyte, producing a measurable chemical or physical change. The transducer then converts this biological signal into a quantifiable electrical signal, allowing for the rapid and precise monitoring of substance concentrations in various samples.

87. (D) Glucose oxidase
Most modern glucose biosensors rely on the enzyme glucose oxidase to detect and quantify sugar levels in blood samples. This enzyme specifically catalyzes the oxidation of glucose, producing gluconolactone and hydrogen peroxide. The resulting change in oxygen concentration or the production of peroxide can be measured electronically by a transducer, providing a quick and accurate reading for patients managing diabetes.

NODIA

88. (A) Alter the DNA to modify amino acids and catalytic properties
Site-directed mutagenesis is a fundamental tool in enzyme engineering that allows for the precise modification of a protein's primary sequence by changing specific codons in its DNA. By systematically replacing individual amino acids, researchers can investigate how these residues influence substrate binding, catalytic speed, and overall stability. This rational design approach is essential for creating enhanced enzymes with improved properties for industrial use.

89. (B) Protein solubility at high ionic strength
Salting out is a widely used protein purification technique that exploits the fact that protein solubility decreases as the salt concentration in a solution increases. High concentrations of salts like ammonium sulfate compete for the water molecules needed to solvate the protein's surface. This leads to the exposure of hydrophobic patches and the subsequent precipitation of proteins, allowing them to be separated.

90. (A) P-2, Q-3, R-1, S-4
Enzyme purification relies on several distinct physical principles. Gel filtration chromatography separates molecules based on their size and shape as they pass through a porous matrix. Ion-exchange chromatography exploits differences in net electrical charge, while affinity chromatography utilizes highly specific binding to a ligand. Finally, salting out is a technique

the model to explain both positive and negative cooperative binding behaviors.

73. (D) The final product of the pathway
Feedback inhibition is a sophisticated regulatory mechanism where the end-product of a metabolic pathway acts as an inhibitor for an enzyme that functions earlier in the same sequence. By binding to a regulatory site, the final product can slow down its own synthesis when concentrations become high. This prevents the wasteful overproduction of metabolites and helps maintain homeostatic balance within the cell.

74. (D) Irreversible covalent modification
Zymogen activation involves the conversion of an inactive enzyme precursor into its active form through the selective cleavage of specific peptide bonds. This proteolytic process is a form of covalent modification that is fundamentally irreversible, as the removed peptide fragments cannot be easily reattached. This mechanism ensures that potent enzymes, such as digestive proteases, are only activated when and where they are actually needed.

75. (B) I, II and IV
Zymogens like trypsinogen and chymotrypsinogen are synthesized in the pancreas and stored in an inactive form to prevent self-digestion of the tissue. They are activated through specific proteolytic cleavage, a process that is irreversible and does not require the input of energy from adenosine triphosphate. This regulatory mechanism is essential for the safe and controlled release of powerful digestive enzymes into the intestine.

76. (B) Phosphorylation
Phosphorylation is the most prevalent and well-studied method of reversible covalent modification used to regulate enzyme activity in eukaryotic cells. This process involves the addition of a phosphate group to specific amino acid residues, typically using adenosine triphosphate as the donor. The resulting change in charge and structure can either activate or inhibit the enzyme, providing a rapid way to control metabolic fluxes.

77. (A) Serine, Threonine, Tyrosine
Protein kinases are specialized enzymes that regulate cellular processes by attaching phosphate groups to the hydroxyl side chains of specific amino acids. The most common targets for this modification are serine, threonine, and tyrosine residues. These particular amino acids are chosen because their chemical properties allow for the stable yet reversible attachment of phosphate, which serves as a molecular switch for protein function.

78. (C) Different physical forms of an enzyme catalyzing the same reaction
Isoenzymes are distinct molecular forms of the same enzyme that catalyze identical chemical reactions but differ in their primary protein structure. These variations often result in different kinetic properties, regulatory sensitivities, or tissue-specific expressions. Isoenzymes allow an organism to fine-tune its metabolism to meet the specific physiological requirements of different organs or developmental stages while maintaining a consistent overall chemical process.

79. (D) 5
Lactate dehydrogenase is a tetrameric enzyme composed of two different types of subunits, known as H and M. These subunits can combine in five distinct ways to form various isoenzymes, ranging from all-H to all-M configurations. These five forms are distributed differently across tissues like the heart and muscle, allowing for specialized regulation of anaerobic metabolism throughout the human body.

80. (A) Evolutionary mutations in key catalytic residues
Pseudoenzymes are proteins that share significant structural similarity with active enzymes but lack the ability to perform catalysis. This loss of function is typically caused by evolutionary mutations that have altered or removed essential amino acids within the active site. Despite being catalytically "dead," pseudoenzymes often remain important in biology by serving as structural scaffolds, signaling regulators, or competitive binding partners.

81. (A) Catalyze distinct reactions or accept diverse substrates
Enzyme promiscuity refers to the ability of a single enzyme to facilitate chemical transformations other than its primary, physiologically relevant reaction or to act upon a wide range of different substrates. This inherent flexibility is often found in enzymes that have not yet reached extreme specialization and is thought to play a critical

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amino group is fundamental for the synthesis and degradation of all protein-building blocks.

100. (A) Thiamine pyrophosphate (TPP)
Vitamin B_1, or thiamine, is biologically active only after it has been converted into its coenzyme form, thiamine pyrophosphate. This molecule is required by several critical enzymes, such as pyruvate dehydrogenase, which are involved in the decarboxylation of alpha-keto acids. By facilitating these reactions, thiamine pyrophosphate plays a central role in the bridge between glycolysis and the citric acid cycle.

101. (A) Collagen
Vitamin C, or ascorbic acid, serves as an essential co-substrate for enzymes that facilitate the hydroxylation of proline and lysine residues during the synthesis of collagen. This structural protein is the primary component of connective tissues, including skin, blood vessels, and bones. Without sufficient vitamin C, the collagen fibers produced are unstable and weak, leading to the clinical symptoms of tissue breakdown.

102. (C) Pantothenic acid
Pantothenic acid is a water-soluble vitamin that forms a core structural part of Coenzyme A, a vital molecule in cellular metabolism. Coenzyme A acts as a carrier for acyl groups, facilitating the entry of carbon fragments into the citric acid cycle and participating in fatty acid synthesis. Because of this central role, pantothenic acid is essential for the liberation of energy from all macronutrients.

103. (B) Vitamin B_2
Riboflavin, which is also known as Vitamin B_2, serves as the direct precursor for the synthesis of the coenzymes flavin mononucleotide and flavin adenine dinucleotide. These molecules are essential components of various oxidoreductase enzymes that participate in oxidation-reduction reactions throughout metabolism. Their ability to accept and donate electrons is critical for energy production within the mitochondria during the process of cellular respiration.

104. (D) Carboxylation reactions
Biotin is a water-soluble vitamin that functions as a prosthetic group for a specific set of enzymes called carboxylases. These enzymes facilitate the addition of carbon dioxide to various substrates, a process that is essential for gluconeogenesis, fatty acid synthesis, and the metabolism of certain amino acids. Biotin remains covalently attached to the enzyme, acting as a swinging arm to transport activated carbon dioxide.

105. (C) A is true but R is false.
Vitamin B_{12} is crucial for maintaining healthy nerve cells and red blood cells, and its deficiency is a known cause of pernicious anemia. However, the claim that it is absorbed without help is incorrect. In reality, vitamin B_{12} requires a specific protein called intrinsic factor, secreted by the stomach, to be successfully absorbed in the terminal ileum of the small intestine.

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106. (D) One-carbon metabolism
Folic acid must be converted into its active form, tetrahydrofolate, to participate in vital cellular processes known collectively as one-carbon metabolism. This pathway involves the transfer of single carbon units, which are essential for the synthesis of purines and thymidylate needed for DNA replication. Consequently, folic acid is critical for rapidly dividing cells and is particularly important during embryonic development.

107. (A) Vitamin A
Vitamin A is a fat-soluble nutrient that is essential for several biological functions, most notably the process of vision. In the retina, a derivative of vitamin A called retinal combines with the protein opsin to form rhodopsin, the light-sensitive pigment in rod cells. This molecule allows the eye to detect low levels of light, making vitamin A vital for maintaining normal vision in dim conditions.

108. (B) 1,25-dihydroxycholecalciferol (Calcitriol)
Vitamin D is obtained from the diet or synthesized in the skin but must undergo two successive hydroxylation steps to become functional. The first occurs in the liver and the second in the kidneys, resulting in the formation of calcitriol. This molecule is the most potent hormonal form of vitamin D and is responsible for regulating calcium absorption and bone mineralization in the body.

109. (C) Lipid-soluble antioxidant
Vitamin E, primarily found in the form of alpha-tocopherol, is a powerful fat-soluble antioxidant that protects cell membranes from oxidative damage. It functions by neutralizing reactive

that manipulates solubility through changes in the salt concentration of the medium.

91. (B) Adding a free ligand that competes for the enzyme
In affinity chromatography, the target enzyme is selectively captured by a ligand that is covalently attached to the stationary phase of the column. To recover the purified enzyme, a solution containing a high concentration of the free ligand or a structural analog is passed through. The free ligand competes for the enzyme's binding site, causing the enzyme to dissociate from the column and elute.

92. (A) Total enzyme units divided by total milligrams of protein
Specific activity is a critical parameter used to assess the purity of an enzyme preparation throughout the isolation process. It is calculated by dividing the total catalytic activity, expressed in units, by the total mass of protein present in the sample. As non-target proteins are removed during purification, the total protein decreases while the activity remains concentrated, leading to a higher value.

93. (C) Increases as purity increases
During the various stages of a protein purification protocol, the goal is to selectively remove unwanted cellular proteins while retaining the target enzyme. As the total amount of protein in the sample decreases relative to the amount of active enzyme, the calculated specific activity will consistently rise. Therefore, a significant increase in this value serves as a reliable indicator of a successful purification step.

94. (A) Dividing final specific activity by initial specific activity
The fold-purification value is a measure of how much the purity of an enzyme has increased relative to the starting material. It is determined by taking the specific activity of the enzyme after a purification step and dividing it by the specific activity of the crude extract. This ratio helps researchers evaluate the effectiveness and efficiency of different chromatographic or precipitation techniques.

95. (B) Biofuel production and textile processing
Cellulases are industrial enzymes that break down cellulose into fermentable sugars, making them indispensable for the large-scale production of biofuels from plant biomass. In the textile industry, these enzymes are used for processes like bio-polishing to remove surface fuzz and for creating the "stone-washed" appearance in denim. Their ability to specifically degrade plant fibers provides an environmentally friendly alternative to harsh chemicals.

96. (D) Hydrolyze starch into simple sugars
Amylases are a group of enzymes that specialize in the breakdown of starch molecules into smaller sugars like maltose and glucose. They are extensively used in various industries, including food processing for brewing and baking, and in the textile industry for removing starch-based sizing agents from fabrics. Their ability to rapidly liquefy and saccharify starch makes them highly valuable for agricultural and industrial applications.

97. (A) Recombinant DNA technology
Restriction endonucleases are essential biological tools that function by cutting DNA at very specific nucleotide sequences. Their ability to generate precise fragments of genetic material has revolutionized molecular biology and is the cornerstone of recombinant DNA technology. By allowing scientists to isolate and join DNA from different sources, these enzymes enable gene cloning, genetic engineering, and various forms of forensic analysis.

98. (A) Urokinase (Tissue plasminogen activator)
Certain enzymes are used as life-saving therapeutic agents, particularly in the management of cardiovascular emergencies. Urokinase and tissue plasminogen activator are examples of thrombolytic enzymes that function by dissolving blood clots that block coronary arteries. By initiating the breakdown of fibrin, these enzymes can restore blood flow to the heart muscle during an acute myocardial infarction, significantly improving patient outcomes and survival rates.

99. (C) Pyridoxine (B_6)
Pyridoxine, also known as Vitamin B_6, is converted into its active coenzyme form, pyridoxal phosphate, which is absolutely essential for amino acid metabolism. Specifically, it acts as a cofactor for transaminases, which transfer amino groups between molecules. This vitamin's ability to form a temporary chemical linkage with the

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not reduced, as the enzyme can still reach its full catalytic capacity.

64. (D) The enzyme-substrate (ES) complex
Uncompetitive inhibition involves an inhibitor that binds exclusively to the complex formed after the substrate has already attached to the enzyme. Because the inhibitor does not compete for the free active site, it cannot be overcome by adding more substrate. This binding stabilizes the enzyme-substrate complex, preventing it from proceeding to the product-forming step and thereby reducing the overall efficiency of the reaction.

65. (B) Both $V_{\max}$ and K_m decrease
Uncompetitive inhibition leads to a simultaneous reduction in both the maximum reaction velocity and the apparent Michaelis constant. The decrease in $V_{\max}$ occurs because the inhibitor effectively removes a portion of the enzyme-substrate complexes from the catalytic pool. The decrease in K_m happens because the binding of the inhibitor shifts the equilibrium toward the complex, appearing to increase the enzyme's affinity for the substrate.

66. (C) In the second or third quadrant
Mixed inhibition occurs when an inhibitor can bind to both the free enzyme and the enzyme-substrate complex, but with different affinities for each form. This results in changes to both the maximum velocity and the Michaelis constant. On a double-reciprocal plot, the lines representing the inhibited and uninhibited reactions will intersect at a point that is not located on either the vertical or horizontal axis.

67. (B) The affinity for the free enzyme and the ES complex is identical
Non-competitive inhibition is a specific type of mixed inhibition where the inhibitor binds to a site other than the active site with equal affinity for both the free enzyme and the enzyme-substrate complex. This binding reduces the total amount of active enzyme without affecting the substrate's ability to bind. Therefore, the maximum velocity decreases while the Michaelis constant remains completely unaffected by the inhibitor.

68. (A) Competitive
Competitive inhibitors are the only class of reversible inhibitors that can be entirely displaced by an excess of substrate. Since the inhibitor and substrate compete for the same active site, increasing the substrate concentration shifts the binding equilibrium in favor of the substrate. This allows the reaction to eventually reach its original maximum velocity, even if the apparent affinity of the enzyme is reduced.

69. (B) Parallel lines
Uncompetitive inhibition produces a unique signature on a Lineweaver-Burk plot, characterized by a series of parallel lines as the inhibitor concentration is increased. This occurs because the inhibitor reduces both the maximum velocity and the Michaelis constant by the same proportional factor. The lack of an intersection point on the graph is the defining diagnostic feature for this specific type of reversible enzyme inhibition.

70. (B) Sigmoidal
Allosteric enzymes typically do not follow the standard hyperbolic kinetics described by the Michaelis-Menten model. Instead, they exhibit a sigmoidal or S-shaped curve when reaction velocity is plotted against substrate concentration. This behavior is a result of cooperative interactions between multiple subunits, where the binding of a substrate molecule to one site influences the affinity and activity of the remaining sites.

71. (A) All subunits in the oligomer must exist in the same conformational state
The Monod-Wyman-Changeux model, also known as the symmetry model, proposes that all subunits of an allosteric enzyme must simultaneously exist in the same conformation, either the Tense or Relaxed state. The entire oligomer transitions between these states in a concerted fashion to maintain symmetry. This model effectively explains positive cooperativity but does not account for the phenomenon of negative cooperativity.

72. (C) Conformational changes occur sequentially within individual subunits
The Koshland-Némethy-Filmer model, or the sequential model, suggests that subunits of an allosteric enzyme can undergo conformational changes independently. When a substrate binds to one subunit, it induces a change in that specific subunit, which then alters the interactions with neighboring subunits without requiring them to change state immediately. This flexibility allows

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oxygen species and free radicals that can cause lipid peroxidation within the phospholipid bilayer. By maintaining the integrity of these membranes, vitamin E plays a crucial role in preventing various chronic diseases and supporting overall cellular health.

110. (C) Gamma-carboxylation of glutamate residues
Vitamin K is an essential cofactor for an enzyme that performs the post-translational modification of several blood clotting factors, including prothrombin. This modification involves the addition of a carboxyl group to specific glutamate residues, allowing the proteins to bind calcium ions. This calcium-binding ability is necessary for the clotting factors to associate with membranes and initiate the coagulation cascade during injury.

111. (A) Vitamin A
Night blindness is often one of the earliest clinical signs of a significant deficiency in vitamin A. This condition occurs because the body cannot produce enough rhodopsin, the pigment required for vision in low-light environments. If left untreated, severe vitamin A deficiency can lead to more serious eye damage, including xerophthalmia and permanent blindness, particularly in populations with limited access to nutrient-rich foods.

112. (C) Ascorbic acid
Scurvy is a nutritional deficiency disease caused by a severe lack of vitamin C, or ascorbic acid. The primary biochemical reason for the symptoms is the failure of collagen synthesis, which requires vitamin C as a cofactor. This results in weakened connective tissues, leading to fragile blood vessels, internal bleeding, swollen and bleeding gums, and significantly delayed wound healing throughout the body.

113. (A) Thiamine
Beriberi is a disease resulting from a chronic deficiency of thiamine, also known as vitamin B1. Because thiamine is essential for carbohydrate metabolism and energy production, its absence severely affects the nervous system and the heart. The disease can manifest in two forms: dry beriberi, characterized by nerve damage and muscle wasting, and wet beriberi, which involves cardiovascular failure and swelling.

114. (C) Vitamin D
Vitamin D is essential for maintaining proper levels of calcium and phosphorus, which are the primary minerals needed for bone formation. A deficiency in this vitamin leads to impaired mineralization of the skeletal system. In children, this results in rickets, characterized by soft and deformed bones, while in adults, it causes osteomalacia, leading to increased bone fragility and pain.

115. (A) Pellagra
Pellagra is a clinical condition caused by a severe deficiency of niacin, which is vitamin B3, or its precursor tryptophan. The disease is classically characterized by the "three Ds": dermatitis, diarrhea, and dementia. Without sufficient niacin, the body cannot produce enough nicotinamide adenine dinucleotide, which is required for numerous metabolic reactions, eventually leading to widespread systemic failure if not corrected.

116. (A) Bind to surface receptors and activate second messengers
Peptide hormones are water-soluble molecules that cannot easily cross the hydrophobic lipid bilayer of cell membranes. Instead, they exert their physiological effects by binding to specific receptor proteins located on the surface of target cells. This binding event triggers an intracellular signaling cascade, often involving second messengers like cyclic AMP, which then alters the activity of various proteins within the cell.

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117. (A) Cyclic AMP (cAMP)
Cyclic adenosine monophosphate is a fundamental second messenger used by many peptide hormones to relay signals from the cell surface to the interior. When a hormone binds to its G-protein coupled receptor, it activates the enzyme adenylate cyclase, which converts adenosine triphosphate into cAMP. This messenger then activates protein kinases that modify target proteins, leading to a specific physiological response.

118. (C) Binding to receptors acting as transcription factors
Steroid hormones are lipid-soluble molecules that can readily diffuse through the plasma membranes of target cells. Once inside, they bind to specific intracellular receptors located in the cytoplasm or the nucleus. The resulting

While the Lineweaver-Burk plot uses reciprocal values on both axes, its slope is actually defined by the ratio of the Michaelis constant to the maximum velocity. Stating that the slope is the inverse of this ratio is incorrect, making this specific combination the only inaccurate representation among the common linear plotting techniques.

46. (B) $\frac{1}{V_{max}}$

The Hanes-Woolf plot linearizes the Michaelis-Menten equation by plotting the ratio of substrate concentration to initial velocity against the substrate concentration. In this graphical format, the resulting straight line has a slope that is mathematically equivalent to the reciprocal of the maximum velocity. This feature allows researchers to easily determine the V_{max} and is appreciated for its relatively even distribution of experimental data.

47. (A) Sequential mechanism

A sequential mechanism describes a multi-substrate enzymatic reaction where all necessary substrate molecules must bind to the enzyme's active site before any product can be released. This process typically involves the formation of a ternary complex consisting of the enzyme and both substrates. Depending on the enzyme, the binding of these substrates can occur in a specific order or randomly.

48. (C) There is an obligatory order for substrate binding

In an ordered sequential bisubstrate reaction, the enzyme requires that the substrates bind to the active site in a very specific and non-random sequence. The first substrate must bind before the second substrate can be accommodated, and similarly, the products must also be released in a defined order. This mechanism is common for many enzymes that utilize cofactors like nicotinamide adenine dinucleotide.

49. (D) The transient covalent modification of the enzyme

The Ping-Pong or double-displacement mechanism is a multi-substrate process where the first substrate binds and reacts to release the first product before the second substrate even enters. During this sequence, a functional group is transferred from the first substrate to the enzyme, creating a transiently modified covalent intermediate. This modified enzyme then reacts with the second substrate to complete the overall catalytic cycle.

50. (C) Ping-Pong

Aminotransferases are classic examples of enzymes that follow a Ping-Pong kinetic mechanism during the transfer of amino groups between molecules. In the first step, an amino acid donates its amino group to the enzyme's prosthetic group, pyridoxal phosphate, releasing a keto acid. The resulting modified enzyme then transfers the amino group to a different keto acid, thereby regenerating the original enzyme form.

51. (B) Parallel lines in a double-reciprocal plot

In enzyme kinetics, the Ping-Pong mechanism is easily distinguished from sequential mechanisms by its characteristic appearance on a Lineweaver-Burk plot. When the reciprocal of velocity is plotted against the reciprocal of one substrate at various fixed concentrations of the second substrate, the result is a series of parallel lines. This pattern indicates that the maximum velocity and Michaelis constant change in a coordinated manner.

52. (D) Lines intersecting to the left of the y-axis

Sequential multi-substrate reactions are characterized by the formation of a ternary complex, which produces a distinct pattern in double-reciprocal plots. When the concentration of one substrate is varied while the other is held at different fixed levels, the resulting lines will intersect at a common point located to the left of the vertical axis. This intersection confirms that all substrates bind before catalysis.

53. (A) Ping-Pong

Isotope exchange experiments are a powerful tool for diagnosing enzymatic mechanisms. If an enzyme can facilitate the exchange of an isotope between a substrate and a product in the absence of the second substrate, it strongly indicates a Ping-Pong mechanism. This occurs because the enzyme forms a covalently modified intermediate that can react back with the product to reform the original substrate molecule.

54. (C) Proton transfers mediated by weak acids/bases other than water

General acid-base catalysis involves the transfer of protons to or from the substrate using specific

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These actions ensure that the body has a steady supply of energy during extended periods of physical or emotional strain.

128. (C) Adrenal cortex hormones (cortisol and aldosterone)
Addison's disease is a chronic endocrine disorder characterized by the primary failure of the adrenal cortex to produce sufficient amounts of steroid hormones. The most significant deficiencies involve cortisol, which regulates metabolism and stress, and aldosterone, which maintains fluid and electrolyte balance. Patients with this condition often experience fatigue, low blood pressure, and a characteristic darkening of the skin due to hormonal imbalances.

129. (B) Glucagon
The islets of Langerhans in the pancreas contain several types of specialized endocrine cells. The alpha cells are specifically responsible for the synthesis and secretion of glucagon, a hormone that raises blood glucose levels. Glucagon acts primarily on the liver to stimulate the breakdown of glycogen and the synthesis of new glucose, providing an essential counter-balance to the effects of insulin.

130. (C) Facilitating glucose uptake into tissues
Insulin is a peptide hormone that plays a central role in regulating energy metabolism by lowering blood glucose levels. Its primary mechanism of action is to stimulate the translocation of glucose transporter proteins to the cell membranes of muscle and adipose tissues. This facilitates the rapid uptake of glucose from the bloodstream into these cells for storage or immediate energy use.

131. (A) Autoimmune destruction of pancreatic beta cells
Type 1 diabetes mellitus is an autoimmune disease where the body's own immune system mistakenly attacks and destroys the insulin-producing beta cells in the pancreas. This leads to a severe or total lack of insulin, preventing the body from regulating blood glucose levels. As a result, patients with this condition require lifelong insulin therapy to maintain normal metabolism and prevent serious complications.

132. (B) Cholesterol
All steroid hormones, including testosterone, estrogen, and cortisol, are derived from a common precursor molecule known as cholesterol. Through a series of complex enzymatic steps occurring in the mitochondria and endoplasmic reticulum of specialized cells, cholesterol is converted into various active hormones. This shared biosynthetic pathway explains why these molecules have similar four-ring structures and are inherently lipid-soluble.

133. (C) Auxins
Auxins are a class of plant hormones that play a dominant role in coordinating growth and development. One of their most famous effects is apical dominance, where the auxin produced in the terminal bud travels down the stem to inhibit the growth of lateral buds. This ensures that the plant prioritizes upward growth toward light rather than becoming excessively bushy.

134. (A) Auxin
Indole-3-acetic acid is the most prevalent and significant naturally occurring member of the auxin family in plants. It regulates a wide array of physiological processes, including cell elongation, root initiation, and tropisms like phototropism and gravitropism. Because of its central importance, indole-3-acetic acid is often used interchangeably with the term auxin in many botanical and agricultural contexts.

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135. (A) II, IV, I, III
Auxin signaling begins when the hormone binds to its receptor, TIR1. This binding event allows the receptor to interact with a specific ubiquitin ligase complex, which then targets repressor proteins for degradation. Once these inhibitors are removed, auxin response factors are freed to activate the transcription of target genes. This sequence allows the plant to rapidly adjust its growth in response to hormone levels.

136. (D) Auxins
Auxins are unique among plant hormones because they undergo polar transport, moving specifically from the shoot tip toward the base of the plant. This directional movement is facilitated by specialized carrier proteins located at the bottom of each cell. This regulated transport creates concentration gradients that are essential for establishing the plant's overall architecture and directing its response to environmental stimuli.

137. (B) Gibberellin
Gibberellins are a diverse group of plant hormones best known for their ability to promote dramatic stem elongation by stimulating both cell division and cell expansion. They are also critical for breaking seed dormancy and initiating germination by inducing the synthesis of enzymes that break down stored starch. These properties make them essential for the normal growth and reproductive success of many plant species.

138. (B) Terpenoid (isoprenoid) pathway
The biosynthesis of gibberellins occurs via the complex terpenoid pathway, which also produces other important plant molecules like carotenoids and chlorophyll. This pathway starts with simple five-carbon units and involves several enzymatic steps in the plastids and endoplasmic reticulum. Understanding this biosynthetic route is important for agricultural applications, as chemical inhibitors of this pathway are often used as plant growth retardants.

139. (A) Adenine
Cytokinins are a class of plant hormones that are chemically derived from the nitrogenous base adenine. They were first discovered for their ability to promote cytokinesis, or cell division, in tissue culture. Beyond this role, they are important for regulating leaf senescence, nutrient mobilization, and the development of chloroplasts. Their structure typically consists of an adenine ring with a side chain attached.

140. (B) Shoots
In plant biotechnology, the relative concentrations of auxin and cytokinin are used to control the development of tissues in culture. When the ratio of cytokinin to auxin is high, the undifferentiated cells are stimulated to develop into shoots. Conversely, a low ratio favors the formation of roots. This ability to manipulate plant growth through hormonal balance is fundamental for the regeneration of whole plants from single cells.

141. (D) Volatile gas
Ethylene is a unique plant hormone because it exists as a simple, two-carbon gaseous molecule. Being volatile allows ethylene to diffuse easily through plant tissues and even move between different plants in the environment. This gaseous nature is essential for its role in coordinating large-scale processes like fruit ripening and leaf abscission, where the signal must be synchronized across many different cells.

142. (D) 1-Aminocyclopropane-1-carboxylic acid (ACC)
In higher plants, the final and most critical step in the biosynthesis of ethylene is the conversion of 1-aminocyclopropane-1-carboxylic acid. This molecule is formed from the amino acid methionine through a regulated pathway. The enzyme ACC oxidase then catalyzes the oxidation of this precursor to produce the active ethylene gas, representing a key regulatory point for managing fruit ripening and stress responses.

143. (A) Abscisic acid (ABA)
Abscisic acid is often referred to as the "stress hormone" because it plays a primary role in helping plants survive unfavorable environmental conditions like drought. When a plant experiences water deficit, levels of this hormone rise rapidly, signaling the guard cells of the stomata to close. This physiological response reduces water loss through transpiration, allowing the plant to conserve its internal moisture during dry periods.

144. (B) Gibberellin
The regulation of seed germination in plants is largely controlled by the antagonistic relationship between abscisic acid and gibberellin. While gibberellins promote germination by stimulating the mobilization of nutrient reserves, abscisic acid acts to maintain seed dormancy and prevent premature sprouting. The balance between these two hormones determines whether a seed will remain dormant or begin its growth into a new plant.

145. (D) Pathogen defense
Salicylic acid is a critical signaling molecule involved in the plant's immune response to pathogenic microorganisms. When a plant is attacked, levels of this phenolic compound increase, triggering a series of defense mechanisms both at the site of infection and throughout the entire plant. This process, known as systemic acquired resistance, helps the plant protect itself against a wide range of future infections.

146. (A) Animal steroid hormones
Brassinosteroids are a group of polyhydroxylated steroid hormones in plants that share a high degree of structural similarity with the steroid hormones found in animals, such as cholesterol-

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derived hormones. They are essential for normal plant growth, participating in cell expansion, vascular differentiation, and pollen development. Their discovery highlights that both plants and animals have evolved similar chemical strategies to regulate complex physiological processes using steroids.

147. (C) Stimulate fungal interaction
Strigolactones are a relatively recently identified class of plant hormones that perform multiple functions both inside and outside the plant. One of their most ecologically significant roles is to act as signaling molecules in the soil, attracting beneficial mycorrhizal fungi to the plant roots. This interaction enhances the plant's ability to absorb nutrients like phosphorus, providing a significant advantage for survival in nutrient-poor environments.

148. (C) BRI1 (a leucine-rich repeat receptor kinase)
The signaling of brassinosteroids is initiated when the hormone binds to its primary receptor, BRI1, which is located on the surface of plant cells. This receptor is a leucine-rich repeat receptor-like kinase that spans the plasma membrane. Upon hormone binding, BRI1 undergoes phosphorylation and triggers an internal cascade that ultimately regulates the activity of specific transcription factors, leading to changes in plant growth.

149. (A) Carotenoid pathway
Strigolactones are biosynthesized from carotenoids, which are the same pigments responsible for the yellow and orange colors in many plants. This biosynthetic route involves several enzymatic steps that cleave and rearrange the carotenoid molecules to form the characteristic lactone structure of strigolactones. Understanding this connection helps researchers study how plants balance their investment in pigments and hormone-driven growth strategies.

150. (A) P-2, Q-1, R-4, S-3
Plant hormones coordinate various life processes through specialized signaling pathways. Ethylene is primarily responsible for the rapid ripening of fruits, while abscisic acid mediates the closure of stomata during water stress. Salicylic acid is a key player in the systemic defense against pathogens, and strigolactones are essential for initiating the symbiotic interaction between roots and beneficial soil fungi.

151. (A) It discriminates between closely related structural stereoisomers
Enzyme specificity is one of the most remarkable features of biological catalysis, allowing enzymes to distinguish between nearly identical molecules. A consequence of this high selectivity is the ability of enzymes to differentiate between stereoisomers, such as L-amino acids and D-amino acids. This ensures that metabolic pathways proceed with extreme precision, as the enzyme's active site is uniquely tailored to fit only one specific spatial arrangement.

152. (C) It does not change the overall free energy requirement
Catalysis is a kinetic process that speeds up the rate of a reaction by lowering the activation energy barrier. However, it is important to note that enzymes do not alter the underlying thermodynamics of a reaction. In an endergonic process, the final state still has higher free energy than the initial state, and the enzyme cannot make the reaction spontaneous without an external energy source.

153. (A) Substrate molecule
Competitive inhibitors are designed or evolved to mimic the structural and chemical properties of an enzyme's natural substrate. Because of this similarity, the inhibitor can bind directly to the active site, effectively blocking the substrate from entering. This mode of inhibition is reversible and depends on the relative concentrations of the substrate and the inhibitor, highlighting the importance of structural complementarity in enzyme binding.

154. (A) $V_{\max}$ decreases, K_m remains constant
In pure non-competitive inhibition, the inhibitor binds to a site other than the active site and does not interfere with the substrate's ability to attach to the enzyme. Because the substrate can still bind normally, the Michaelis constant remains unchanged. However, the presence of the inhibitor prevents the catalytic step from occurring, effectively reducing the total amount of functional enzyme and lowering $V_{\max}$ while the K_m remains unchanged.

155. (C) The concentration of the enzyme-substrate complex
According to the fundamental principles of enzyme kinetics, the overall rate of a reaction is directly proportional to the amount of enzyme-substrate

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process large volumes of syrup continuously and reuse the catalyst many times, which is essential for making the process economically viable and efficient.

174. (B) Convert the signal to electrical form
In the design of a biosensor, the transducer is the component responsible for capturing the physical or chemical change produced by the biological recognition element and converting it into a measurable signal. This signal is typically electrical, such as a change in voltage or current. By translating biological information into a digital or analog output, the transducer enables the precise quantification of the target substance.

175. (A) It allows for the targeted alteration of specific amino acids based on structural data
Site-directed mutagenesis is a cornerstone of rational enzyme engineering because it offers precise control over the modifications made to a protein. Unlike random mutagenesis, which introduces changes blindly, site-directed methods allow researchers to use structural information to target specific residues for alteration. This focused approach is much more efficient for studying catalytic mechanisms and for systematically improving the properties of industrial enzymes.

176. (C) Salting out
Salting out is a classic purification technique that involves adding high concentrations of a salt, typically ammonium sulfate, to a protein solution. This process works by reducing the availability of water molecules to solvate the proteins, causing them to aggregate and precipitate out of solution. By carefully adjusting the salt concentration, different proteins can be selectively precipitated based on their unique solubility profiles.

177. (B) 5 units/mg
Specific activity is a measure of enzyme purity and is calculated by taking the total activity of the sample and dividing it by the total protein mass. In this case, dividing 500 units by 100 milligrams yields a specific activity of 5 units per milligram. This value provides a baseline for evaluating how much the purity increases as subsequent purification steps are applied to the extract.

178. (B) The target enzyme was significantly enriched despite some yield loss
In enzyme purification, it is common to experience a decrease in total activity while seeing a significant increase in specific activity. This outcome indicates that while some of the target enzyme was lost during the process, a much larger proportion of contaminating proteins was successfully removed. Therefore, the overall purity and concentration of the remaining enzyme have improved, which is often the primary goal.

179. (C) Size and molecular weight
Gel filtration chromatography, also known as size-exclusion chromatography, separates protein molecules based strictly on their physical dimensions. The stationary phase consists of porous beads that allow smaller molecules to enter and spend more time inside, while larger molecules are excluded and move rapidly around the beads. Consequently, the largest proteins elute from the column first, followed by progressively smaller molecules in a defined order.

180. (D) I, II and III
Enzyme purification utilizes several complementary techniques based on different physical properties. Salting out with ammonium sulfate separates proteins by solubility, while gel filtration chromatography elutes larger molecules more quickly than smaller ones. Affinity chromatography provides the highest level of specificity by exploiting the unique binding of an enzyme to its ligand. Together, these methods allow for the isolation of highly pure enzymes.

181. (D) Affinity chromatography
Affinity chromatography is a powerful separation technique that requires detailed knowledge of an enzyme's biological interactions. To create an effective stationary phase, a specific substrate, inhibitor, or cofactor must be covalently attached to the matrix. This ensures that only the target enzyme binds to the column while all other proteins are washed away, resulting in an exceptionally high degree of purification in a single step.

182. (A) Improving phosphorus availability from phytic acid in animal feed
Phytases are enzymes added to the feed of monogastric animals like pigs and poultry to

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model because it allows individual subunits to change conformation independently. This flexibility is essential for explaining negative cooperativity, where the binding of a substrate to one subunit actually decreases the affinity of the remaining subunits. This phenomenon is a critical regulatory feature for several enzymes but cannot be accommodated by concerted models.

165. (D) A is false but R is true.
Pseudoenzymes are structurally similar to active enzymes and maintain the characteristic protein fold, yet they are catalytically inactive due to the absence of essential amino acids in their active sites. Therefore, the claim that they are highly active catalysts is incorrect. Despite their lack of enzymatic activity, they play vital biological roles as regulatory hubs, scaffolds, and signaling molecules in many pathways.

166. (A) Subunit composition (H and M chains)
The five isoenzymes of lactate dehydrogenase are distinguished by the specific combination of heart and muscle subunits that make up the tetrameric protein. While all five forms catalyze the same interconversion of lactate and pyruvate, their different subunit compositions result in varying kinetic properties and affinities for substrates. This allows different organs to tailor their anaerobic metabolism to their specific physiological needs.

167. (A) A starting point for the evolution of new enzymatic functions
Enzyme promiscuity provides a vital source of biological variation that can be exploited during evolution. When an enzyme possesses a low-level ability to catalyze a secondary reaction, this "side activity" can be improved through natural selection if it provides a survival advantage. Over time, this process can lead to the emergence of entirely new enzymes and pathways, allowing organisms to adapt to new environments.

168. (B) Magnesium (Mg^{2+})
DNA polymerase, the enzyme responsible for replicating genetic material, absolutely requires magnesium ions to function. These inorganic cofactors play a critical role by coordinating with the phosphate groups of the incoming nucleotides and the DNA template. This interaction stabilizes the negative charges and facilitates the nucleophilic attack required for bond formation, making magnesium essential for the accuracy and speed of DNA synthesis.

169. (C) Acyl groups
Coenzyme A is a fundamental metabolic molecule that serves as a versatile carrier for various acyl groups, most commonly acetyl groups. By forming a high-energy thioester bond with these fragments, Coenzyme A activates them for participation in numerous biochemical reactions, including the citric acid cycle and fatty acid metabolism. This makes it a central hub for energy transfer and biosynthesis within the cell.

170. (A) 2 electrons, 1 proton
Nicotinamide adenine dinucleotide is a primary electron carrier in biological systems. During its reduction, the nicotinamide ring of NAD+ accepts a hydride ion, which consists of two electrons and one proton. This transformation results in the formation of NADH, while a second proton is released into the surrounding medium. This efficient movement of electrons is the basis for energy harvesting during cellular respiration.

171. (A) Schiff base
Pyridoxal phosphate, the active form of vitamin B6, initiates its catalytic action by forming a covalent intermediate with the amino group of an amino acid substrate. This specific chemical linkage is known as a Schiff base or an aldimine. The formation of this bond allows the coenzyme to act as an electron sink, facilitating various transformations such as transamination, decarboxylation, and racemization.

172. (B) Antibody enzyme
The term abzyme was coined by combining the words antibody and enzyme to describe a unique class of molecules. These are essentially antibodies that have been engineered or selected to possess catalytic activity, similar to natural enzymes. By mimicking the specificity of the immune system and the catalytic power of enzymes, abzymes represent a powerful bridge between immunology and biocatalysis for research and medicine.

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173. (C) Glucose isomerase
The large-scale production of high-fructose corn syrup relies heavily on the immobilization of the enzyme glucose isomerase. This enzyme facilitates the conversion of glucose into its sweeter isomer, fructose. By immobilizing the enzyme on a solid support, manufacturers can

complex formed. This complex represents the intermediate state where the substrate is positioned within the active site, ready to undergo the chemical transformation. Therefore, any factor that influences the concentration of this complex will have a significant impact on the observed reaction velocity.

156. (A) Low substrate concentrations
An enzyme with a low Michaelis constant has a high affinity for its substrate, meaning it can reach half of its maximum velocity even when the substrate is present in small amounts. Such enzymes are highly effective in cellular environments where metabolites are kept at low concentrations. This high efficiency ensures that vital metabolic processes can continue reliably without requiring the accumulation of large quantities of substrates.

157. (A) $\frac{1}{2} V_{\max}$

The Michaelis constant is mathematically defined as the specific substrate concentration at which the reaction velocity reaches exactly fifty percent of its theoretical maximum. When experimental conditions are set so that the substrate concentration equals the K_m value, the Michaelis-Menten equation simplifies, showing that the initial rate of the reaction is half of the $V_{\max}$. This relationship is a cornerstone of enzyme kinetic analysis.

158. (A) Reciprocal time (e.g., s^{-1})
The turnover number represents a rate of reaction per active site and is calculated by dividing the maximum velocity by the total enzyme concentration. Since this calculation effectively cancels out the units of concentration, the final unit for k_{cat} is expressed as reciprocal time, such as per second. This tells us how many catalytic cycles a single enzyme molecule can complete in one second.

159. (C) Catalytic efficiency ($\frac{k_{cat}}{K_m}$)

The upper limit of enzymatic performance is determined by the physical speed at which molecules can move through water. This diffusion-controlled limit caps the catalytic efficiency of an enzyme, which is the ratio of its turnover number to its Michaelis constant. Enzymes that operate near this limit are considered catalytically perfect, as they react with the substrate almost every time a collision occurs.

160. (A) They consist of multiple subunits exhibiting cooperative binding
Allosteric enzymes are typically complex proteins composed of several interacting subunits. Unlike simple enzymes, the binding of a substrate to one subunit induces a structural change that affects the other subunits, a phenomenon known as cooperativity. This communication between sites results in a sigmoidal kinetic curve rather than the standard hyperbolic curve, allowing for more sensitive and sophisticated regulation of metabolic pathways.

161. (A) Shifting it to the left (increasing apparent affinity)
A positive allosteric modulator acts by binding to a regulatory site and stabilizing the active conformation of an enzyme. This effect increases the enzyme's affinity for its substrate, meaning that less substrate is required to achieve a given reaction velocity. Graphically, this is represented by a leftward shift of the sigmoidal kinetic curve, effectively lowering the substrate concentration needed to reach half-maximal activity.

162. (A) Adenylylation
Adenylylation is a specific form of covalent modification where an adenosine monophosphate group from ATP is covalently attached to a tyrosine residue on a target enzyme. This modification serves as a powerful regulatory switch, often altering the enzyme's activity in response to the energy status of the cell. This process is fully reversible through the action of specialized enzymes that remove the adenyl group.

163. (A) Blood coagulation cascades
The blood coagulation cascade is a prime example of biological regulation through irreversible proteolytic cleavage. Many of the proteins involved in forming a blood clot are synthesized as inactive precursors that must be precisely cut to become functional. Once activated, these enzymes can trigger subsequent steps in the cascade, ensuring a rapid and localized response to vascular injury that cannot be easily reversed.

164. (C) Negative cooperativity
The sequential model of allosterism provides a more flexible framework than the symmetry

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help them digest phytic acid found in plant seeds. Because these animals lack their own phytases, the phosphorus in phytic acid is otherwise unavailable and is excreted, leading to environmental pollution. By breaking down phytic acid, these enzymes improve nutrient absorption and reduce the need for supplemental mineral phosphorus.

183. (A) Detergents for stain removal
Proteases are one of the most widely used classes of industrial enzymes, particularly in the formulation of biological laundry detergents. Their ability to break down protein-based stains, such as those from blood, grass, or food, makes them highly effective cleaning agents. These enzymes are specially engineered to remain stable and active in the presence of the surfactants and high temperatures typically found in washing machines.

184. (D) Taq DNA polymerase
The Polymerase Chain Reaction is a fundamental technique in molecular biology that involves repeated cycles of heating and cooling. This process requires a DNA polymerase that can withstand the high temperatures used to denature DNA without losing its activity. Taq DNA polymerase, isolated from thermophilic bacteria, is the ideal enzyme for this purpose, as it remains stable and functional even at near-boiling temperatures.

185. (A) Acute lymphoblastic leukemia
Asparaginase is a therapeutic enzyme used in the treatment of certain types of cancer, most notably acute lymphoblastic leukemia. Leukemic cells often lack the ability to synthesize their own asparagine and must rely on the supply found in the blood. By breaking down circulating asparagine into aspartic acid, the enzyme effectively starves the cancer cells, leading to their death while sparing healthy cells.

186. (D) Ariboflavinosis
A deficiency in riboflavin, also known as vitamin B2, results in a clinical condition called ariboflavinosis. Symptoms typically include inflammation of the mouth and tongue, cracked skin at the corners of the lips, and sensitivity to light. Because riboflavin is essential for the function of coenzymes in energy metabolism, its lack can cause widespread cellular issues, though severe cases are relatively rare in developed countries.

187. (B) Vitamin B_{12}
Vitamin B_{12} is characterized by one of the most complex molecular structures of all vitamins, featuring a central cobalt ion held within a corrin ring. This unique structural motif is essential for its role as a cofactor in several important metabolic reactions, including DNA synthesis and the maintenance of the myelin sheath around nerves. It is the only vitamin that contains a metallic element.

188. (A) Intrinsic factor secreted by gastric parietal cells
The absorption of vitamin B12 is a highly specialized process that requires the assistance of intrinsic factor, a protein produced by the parietal cells of the stomach. Intrinsic factor binds to the vitamin, protecting it from digestion and allowing it to be recognized by specific receptors in the terminal ileum. Without this crucial protein, even a diet rich in vitamin B12 will result in deficiency and anemia.

189. (A) "Burning feet" syndrome
While pantothenic acid is found in almost all foods, making natural deficiency extremely rare, experimental studies have identified specific symptoms associated with its lack. One of the most characteristic manifestations is known as "burning feet" syndrome, which involves numbness, tingling, and severe pain in the lower extremities. This occurs because the vitamin is essential for synthesizing Coenzyme A, which is vital for nerve function and energy.

190. (A) Fetal neural tube defects
Folic acid supplementation is strongly recommended for women during early pregnancy to ensure the proper development of the fetal nervous system. Sufficient levels of this vitamin are essential for the closure of the neural tube, which eventually forms the brain and spinal cord. Deficiency during this critical period significantly increases the risk of serious birth defects, such as spina bifida and anencephaly.

191. (A) Vitamin A
Beta-carotene is a prominent plant pigment that serves as the primary provitamin precursor for vitamin A in the human diet. When consumed, beta-carotene can be cleaved by enzymes in the

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210. (B) II only
The adrenal gland consists of two distinct regions: the outer cortex and the inner medulla. Cortisol is a glucocorticoid produced exclusively by the adrenal cortex, while the adrenal medulla is responsible for secreting catecholamines like epinephrine. Therefore, the statement pairing cortisol with the adrenal medulla is incorrect. Calcitonin, melatonin, and glucagon are correctly associated with the thyroid, pineal gland, and pancreas, respectively.

211. (A) Binding to nuclear receptors and altering gene transcription
Estradiol is the primary estrogen in humans and exerts its biological effects by diffusing into target cells and binding to specific nuclear receptors. Once the hormone binds, the receptor complex acts as a transcription factor, interacting with DNA to regulate the expression of various genes. This genomic mechanism allows estradiol to coordinate complex physiological processes, such as the menstrual cycle and the development of reproductive tissues.

212. (D) Promotes elongation at lower concentrations than required for stems
Roots and stems have different sensitivities to auxin levels, which is critical for their contrasting growth patterns. While relatively high concentrations of auxin are needed to stimulate cell elongation in stems, the same levels can actually inhibit growth in roots. Roots are much more sensitive and achieve their maximum elongation at much lower concentrations, allowing for precise control of root development in response to soil conditions.

213. (B) Activating proton pumps that lower cell wall pH
According to the acid growth hypothesis, auxin promotes cell elongation by stimulating proton pumps in the plasma membrane to move hydrogen ions into the cell wall. This acidification activates specific enzymes, known as expansins, which loosen the hydrogen bonds within the cell wall matrix. As the wall becomes more flexible, the internal turgor pressure causes the cell to expand and elongate rapidly.

214. (C) Gibberellin
Gibberellins were first discovered in Japan through the study of "foolish seedling" disease in rice, which caused plants to grow excessively tall and spindly before falling over. Researchers found that this abnormal growth was caused by a fungus that produced a chemical later named gibberellic acid. Subsequent studies revealed that gibberellins are natural plant hormones that play a fundamental role in regulating stem elongation and overall plant height.

215. (A) Alpha-amylase
During the germination of cereal seeds, gibberellins are released from the embryo and travel to the aleurone layer of the endosperm. In response, the aleurone cells synthesize and secrete alpha-amylase and other hydrolytic enzymes. These enzymes break down the stored starch into simple sugars, which are then used as fuel for the developing seedling. This mobilization of reserves is essential for successful plant establishment.

216. (B) Root tip meristem
Cytokinins are primarily synthesized in the actively dividing tissues of the root tips. From there, they are transported upward through the xylem to the rest of the plant, where they influence various aspects of development. This upward flow of cytokinins from the roots provides the shoot system with information about the health and activity of the root system, helping the plant coordinate its overall growth.

217. (A) Delay leaf senescence
The Richmond-Lang effect refers to the ability of cytokinins to delay the natural aging process, or senescence, in detached leaves. When treated with this hormone, leaves remain green and physiologically active for a much longer period than untreated leaves. Cytokinins achieve this by promoting nutrient mobilization toward the treated area and preventing the breakdown of chlorophyll and other essential proteins within the leaf.

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218. (A) Ethylene
The "triple response" is a classic physiological reaction observed in dark-grown seedlings when they are exposed to ethylene gas. This response consists of a thickening of the stem, a reduction in longitudinal elongation, and an increase in horizontal growth, often accompanied by the formation of an apical hook. This behavior helps the seedling navigate obstacles as it pushes through the soil toward the surface.

direct neural connection allows for a very fast hormonal response to physiological triggers like dehydration or childbirth.

201. (A) Prolactin
Unlike most pituitary hormones that are primarily regulated by releasing factors, prolactin is unique because its secretion is kept under constant inhibitory control. The hypothalamus secretes dopamine, which acts as the main prolactin-inhibiting factor, preventing the pituitary from producing the hormone unless the inhibition is removed. This negative regulation ensures that prolactin levels remain low except during periods like pregnancy and breastfeeding.

202. (C) Iodine
Iodine is an essential trace element that the thyroid gland requires to synthesize thyroxine and triiodothyronine. When dietary iodine is insufficient, the thyroid cannot produce enough hormones, which triggers the pituitary to release more TSH. The constant stimulation by TSH causes the thyroid gland to enlarge in an attempt to capture more iodine, resulting in a visible swelling in the neck known as a goiter.

203. (B) Low blood calcium levels
The parathyroid glands monitor the concentration of ionized calcium in the blood and respond specifically when levels drop below a certain threshold. In response to low blood calcium, these glands secrete parathyroid hormone, which acts to raise calcium levels by stimulating bone resorption, increasing intestinal absorption, and reducing renal excretion. This rapid hormonal response is critical for maintaining the stability of calcium signaling in the body.

204. (D) Sympathetic nervous system
The adrenal medulla is functionally linked to the sympathetic nervous system and acts as an extension of the body's "fight-or-flight" response. When the sympathetic system is activated during acute stress, it triggers the adrenal medulla to release catecholamines, primarily epinephrine, into the blood. This leads to rapid changes, such as increased heart rate and blood glucose levels, preparing the body for immediate physical action.

205. (A) Sodium retention and potassium excretion
Aldosterone is a mineralocorticoid hormone produced by the adrenal cortex that plays a vital role in regulating blood pressure and electrolyte balance. Its primary action is on the kidneys, where it promotes the reabsorption of sodium ions back into the blood while simultaneously increasing the excretion of potassium ions into the urine. This retention of sodium causes water to follow by osmosis, effectively increasing blood volume.

206. (C) Cortisol
Cushing's syndrome is a hormonal disorder caused by prolonged exposure to excessively high levels of cortisol, either from an overactive adrenal gland, a pituitary tumor, or the use of corticosteroid medications. The excess cortisol leads to a variety of clinical signs, including weight gain in the trunk, a "moon face," high blood pressure, and muscle weakness. Managing this condition involves identifying and treating the underlying cause of the cortisol excess.

207. (A) Inhibit the release of both insulin and glucagon
Somatostatin is produced by the delta cells of the pancreatic islets and acts as a local paracrine regulator of metabolic hormone secretion. Its primary function within the pancreas is to inhibit the release of both insulin and glucagon from the neighboring alpha and beta cells. By moderating the secretion of these two antagonistic hormones, somatostatin helps to fine-tune blood glucose regulation and prevent extreme fluctuations.

208. (A) Hypoglycemia
The secretion of glucagon from the pancreatic alpha cells is primarily triggered by a drop in blood glucose levels, a condition known as hypoglycemia. When glucose is low, glucagon is released to stimulate the liver to convert stored glycogen back into glucose and release it into the bloodstream. This essential survival mechanism ensures that the brain and other tissues have a continuous supply of energy during fasting.

209. (D) Testosterone
In the male reproductive system, luteinizing hormone is secreted by the anterior pituitary and travels to the testes, where it specifically targets the Leydig cells. Upon binding to its receptors, LH stimulates these cells to synthesize and secrete testosterone, the primary male sex hormone. This process is essential for the development of male secondary sexual characteristics and for the maintenance of normal sperm production.

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intestine and liver to produce two molecules of retinal. This makes yellow and orange vegetables, like carrots and sweet potatoes, excellent sources for maintaining healthy vision, immune function, and skin health.

192. (C) Liver, then Kidneys
The activation of vitamin D into its most potent hormonal form is a two-step process occurring in different organs. First, cholecalciferol is converted into 25-hydroxycholecalciferol in the liver. This intermediate then travels through the blood to the kidneys, where it undergoes a second hydroxylation to become 1,25-dihydroxycholecalciferol, also known as calcitriol. This sequential activation ensures that the body can tightly regulate calcium levels.

193. (D) Increasing intestinal absorption and renal reabsorption of calcium
Calcitriol, the active form of vitamin D, plays a central role in maintaining calcium homeostasis by acting on several target tissues. It stimulates the small intestine to increase the absorption of dietary calcium and prompts the kidneys to reduce the amount of calcium excreted in the urine. Together, these actions ensure that there is enough calcium available in the blood for bone mineralization and cellular signaling.

194. (D) Alpha-tocopherol
Among the various forms of vitamin E found in nature, alpha-tocopherol is recognized as the most biologically active and common form in the human body. It is preferentially absorbed and accumulated in tissues, where it serves as a powerful antioxidant protecting lipids from oxidative damage. Because of its high potency and prevalence, most dietary recommendations and nutritional supplements focus specifically on this form of the vitamin.

195. (A) 7-dehydrocholesterol → Cholecalciferol → 25-hydroxycholecalciferol → Calcitriol
The pathway for vitamin D synthesis begins in the skin, where ultraviolet light converts 7-dehydrocholesterol into cholecalciferol. This molecule then undergoes its first activation step in the liver to become 25-hydroxycholecalciferol. Finally, a second activation in the kidneys produces the fully functional hormone, calcitriol. This complex multi-organ pathway highlights the sophisticated regulation required to maintain healthy bones and mineral balance in the body.

196. (D) Vitamin K
Warfarin is a commonly prescribed anticoagulant drug that works by interfering with the recycling of vitamin K within the liver. Vitamin K is essential for the production of several blood clotting factors, and after it is used, it must be regenerated to remain active. By blocking this recycling process, Warfarin reduces the availability of functional vitamin K, thereby slowing down the blood's ability to clot.

197. (A) Prolonged prothrombin time (bleeding tendency)
A primary biochemical indicator of vitamin K deficiency is a significant increase in the time it takes for blood to clot, often measured as prothrombin time. This occurs because vitamin K is necessary for the proper synthesis and activation of key clotting factors. Without enough of this vitamin, the coagulation process is impaired, leading to an increased risk of excessive bleeding and easy bruising.

198. (C) Fat-soluble vitamins
Vitamins A, D, E, and K are fat-soluble and can be stored in the body's fatty tissues and liver for long periods. Because they are not easily excreted in the urine like water-soluble vitamins, they can accumulate to toxic levels if consumed in extreme excess. This condition, known as hypervitaminosis, can lead to serious health problems, including organ damage and severe metabolic disturbances.

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199. (C) Hypophyseal portal system
The hypothalamus communicates with the anterior pituitary through a specialized network of blood vessels known as the hypophyseal portal system. Releasing and inhibiting hormones are secreted into this local blood supply, which carries them directly from the hypothalamus to their target cells in the pituitary. This arrangement allows for rapid and precise control of hormone release with minimal dilution in the general circulation.

200. (B) Posterior pituitary
Oxytocin and antidiuretic hormone are produced by specialized neurons in the hypothalamus. These hormones travel down long nerve fibers to the posterior pituitary, where they are stored in nerve terminals until they are needed. When stimulated, the posterior pituitary releases these hormones directly into the bloodstream. This

219. (B) ACC oxidase
The final step in the biosynthetic pathway of ethylene involves the enzyme ACC oxidase, which converts 1-aminocyclopropane-1-carboxylic acid into ethylene gas. This reaction requires oxygen and produces carbon dioxide and hydrogen cyanide as byproducts. ACC oxidase is a key regulatory enzyme whose activity increases during processes like fruit ripening and in response to environmental stresses, leading to a surge in ethylene production.

220. (B) Lose potassium (K^+) and consequently water
Abscisic acid initiates stomatal closure by triggering a signaling cascade in the guard cells that leads to the opening of potassium efflux channels. As potassium ions leave the cells, the internal osmotic pressure drops, causing water to follow by osmosis. This loss of water makes the guard cells flaccid, causing them to collapse and close the stomatal pore, thereby reducing water loss from the plant.

221. (A) Abscisic acid
Vivipary occurs when seeds germinate while they are still attached to the parent plant, a phenomenon often seen in mutants that cannot produce or respond to abscisic acid. Since ABA is the primary hormone responsible for inducing and maintaining seed dormancy, its absence allow the seeds to bypass the dormant stage and begin growing immediately. This genetic deficiency highlights the essential role of ABA in timing plant reproduction.

222. (A) Shikimate/Isochorismate pathway
In plants, salicylic acid is primarily synthesized through the shikimate pathway, which is also the source of many aromatic amino acids. One major route involves the conversion of isochorismate into salicylic acid. This pathway is highly regulated and its activity increases dramatically when the plant detects a pathogen. The produced salicylic acid then serves as an essential signal for initiating both local and systemic defense responses.

223. (A) Pathogenesis-related (PR) proteins
During the development of systemic acquired resistance, salicylic acid acts as a mobile signal that induces the expression of a specific set of genes throughout the plant. These genes encode pathogenesis-related proteins, which have various antimicrobial properties, such as the ability to degrade fungal cell walls. The accumulation of these proteins provides the plant with long-lasting protection against a broad spectrum of future infections.

224. (B) Brassinosteroid
Brassinosteroids are a class of plant hormones that possess a four-ring steroidal structure very similar to ecdysone, the hormone that regulates molting in insects. This structural analogy is a fascinating example of how similar chemical templates are used across different kingdoms to regulate growth and development. In plants, these steroids are essential for cell expansion and are involved in many aspects of environmental adaptation and stress tolerance.

225. (A) P-4, Q-2, R-3, S-1
Vitamins are essential organic compounds identified by both common letters and specific chemical names. Vitamin B1 is thiamine, while vitamin B3 is niacin. Vitamin C is scientifically known as ascorbic acid, reflecting its role in preventing scurvy. Vitamin B5 is pantothenic acid, a name derived from its widespread presence in nature. Each of these molecules serves as a vital precursor for essential coenzymes in human metabolism.

226. (D) Extreme dwarfism and delayed senescence
Mutants that are unable to produce or sense brassinosteroids exhibit a very distinct phenotype characterized by extreme dwarfism and dark green, crinkled leaves. These plants are significantly smaller than wild-type plants because brassinosteroids are required for normal cell elongation and division. Additionally, these mutants often show delayed senescence and altered reproductive development, emphasizing the hormone's central role in coordinating the entire plant life cycle.

227. (B) Parasitic weed seeds like Striga
Strigolactones were originally discovered as chemical signals in the soil that trigger the germination of parasitic weeds, such as Striga and Orobanche. These parasites have evolved to detect the strigolactones exuded by the roots of host plants, ensuring that they only germinate when a suitable host is nearby to provide nutrients. This specialized signaling relationship is a major challenge in agriculture, leading to significant crop losses in many regions.

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increased, which is a key diagnostic feature used to identify this specific type of enzyme inhibition in the laboratory.

298. (A) Insulin
The insulin receptor is a unique type of cell-surface receptor that possesses intrinsic enzyme activity. When insulin binds to the extracellular part of the receptor, it triggers the internal tyrosine kinase domains to activate and phosphorylate each other. This autophosphorylation event initiates a complex signaling cascade within the cell that regulates glucose uptake, fat storage, and many other aspects of metabolism, making it a central player in hormonal regulation.

299. (C) Transition state stabilization
The original "lock and key" hypothesis proposed that the enzyme's active site was a perfect structural match for the substrate. While this model explained specificity, it failed to account for how enzymes actually lower the activation energy of a reaction. Modern enzymology suggests that the active site is actually most complementary to the high-energy transition state, and the stabilization of this unstable intermediate is the primary source of an enzyme's remarkable catalytic power.

300. (A) I, II, III and V
Plant growth is coordinated by several classes of bioregulators with specialized roles. Brassinosteroids function through membrane-localized receptor kinases to regulate growth, and their absence results in dwarf phenotypes. Strigolactones, derived from carotenoids, are essential for promoting the symbiotic colonization of roots by mycorrhizal fungi. Salicylic acid acts as a crucial signal for the systemic accumulation of defense proteins during pathogen attacks, helping the plant protect itself against widespread infection.

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237. (B) X-ray crystallography
X-ray crystallography is the most powerful and precise technique for determining the three-dimensional structure of enzymes at the atomic level. By analyzing the diffraction pattern of X-rays passing through a crystallized enzyme, researchers can map the exact positions of every atom and residue. This information is invaluable for understanding the structural basis of catalysis and for the rational design of new drugs that target specific active sites.

238. (B) Non-competitive inhibitors reacting with sulfhydryl groups
Many heavy metals, such as lead and mercury, exert their toxic effects by acting as non-competitive inhibitors of various essential enzymes. These metals often have a high affinity for the sulfhydryl groups of cysteine residues located outside the active site. By binding to these groups, the metals can disrupt the enzyme's three-dimensional structure or alter its dynamic properties, leading to a permanent loss of catalytic function.

239. (A) Microenvironment that stabilizes the transition state
The active site of an enzyme is more than just a binding pocket; it provides a unique microenvironment specifically designed to lower the activation energy of a reaction. By using precisely positioned amino acid residues, the active site can provide electrostatic stabilization, facilitate proton transfers, or create strain on the substrate. This specialized environment is optimized to stabilize the high-energy transition state, allowing the reaction to proceed much more rapidly.

240. (D) A is false but R is true.
While it is true that protein kinases add phosphate groups to enzymes to alter their conformation and function, this modification does not always lead to activation. Depending on the specific enzyme and the site of modification, phosphorylation can either turn an enzyme on or off. For instance, while it activates glycogen phosphorylase, it inhibits glycogen synthase. Therefore, phosphorylation serves as a versatile bi-directional switch for metabolic control.

241. (C) Ping-Pong
A Ping-Pong mechanism is uniquely characterized by the release of the first product from the enzyme before the second substrate has even bound to the active site. This occurs because the reaction proceeds in two distinct stages, with the enzyme becoming transiently modified after the first step. This modified enzyme then reacts with the second substrate to produce the second product and regenerate the original form of the enzyme.

242. (A) Covalently modified state
During a Ping-Pong reaction, the enzyme functions as a temporary carrier for a chemical group being transferred between substrates. After the first substrate reacts and releases the first product, the enzyme is left in a covalently modified state, holding the transferred group. This intermediate form of the enzyme must then react with the second substrate to complete the transfer and return the enzyme to its original, unmodified state.

243. (A) $[S]$
The Hanes-Woolf plot is a linear representation of enzyme kinetics where the concentration of the substrate is plotted on the horizontal x-axis. On the vertical y-axis, the ratio of the substrate concentration to the initial velocity is plotted. This arrangement yields a straight line with a slope of one over $V_{\max}$ and an x-intercept of negative K_m, providing an accurate method for determining these fundamental kinetic parameters.

244. (C) 10^8 to 10^9 $M^{-1}s^{-1}$
An enzyme is considered to have reached catalytic perfection when its efficiency ratio, k_{cat} over K_m, approaches the physical limit set by the diffusion of molecules in water. This limit is typically in the range of ten to the eighth to ten to the ninth per molar per second. At this stage, the enzyme is so efficient that every collision with a substrate molecule results in a successful reaction.

245. (A) Prevents the unnecessary overaccumulation of metabolic end-products
Feedback inhibition is a critical biological control mechanism that allows cells to regulate their metabolic output based on current needs. By inhibiting an early enzyme in a pathway when the final product is abundant, the cell avoids the wasteful consumption of energy and resources. This ensures that metabolic intermediates do not accumulate to toxic levels and that the pathway

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only operates when the end-product is actually required.

246. (A) Catalysis by RNA folding and transition state stabilization
Ribozymes are a class of RNA molecules that possess catalytic activity, demonstrating that proteins are not the only biological catalysts. Similar to protein enzymes, ribozymes function by folding into complex three-dimensional shapes that create an active site. Within this site, the RNA can position metal ions and use its own nucleotides to stabilize the transition state of a chemical reaction, most commonly involving the cleavage of phosphodiester bonds.

247. (A) Retain significant regulatory or scaffolding roles
Although pseudoenzymes have lost their primary catalytic ability through evolution, they remain essential components of biological systems. Instead of performing chemical reactions, they often function as structural scaffolds that bring other proteins together or as regulators that modulate the activity of active enzymes. By acting as "competitive binders" or molecular switches, pseudoenzymes provide an additional layer of complexity to cellular signaling and metabolic control.

248. (A) High specificity and rapid reaction rates
Enzymes are ideal for use in environmental biosensors because they offer exceptional specificity for their target pollutants and can catalyze reactions at very high speeds. This allows for the sensitive and rapid detection of specific substances, even in complex mixtures like soil or water. The ability of enzymes to provide real-time information with high accuracy makes them indispensable for monitoring environmental health and identifying potential contamination.

249. (C) It consistently increases the intrinsic kcat of the enzyme
While the immobilization of enzymes provides many industrial benefits, such as easier catalyst recovery and improved stability, it does not typically increase the intrinsic turnover number of the enzyme. In fact, immobilization can often lead to a slight decrease in $k_{\{cat\}}$ because the process may partially restrict the enzyme's flexibility or obstruct its active site. However, the gains in operational stability usually outweigh any minor loss in individual enzyme speed.

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250. (A) Polymerase Chain Reaction (PCR)
Site-directed mutagenesis is technically enabled by the Polymerase Chain Reaction, which allows for the rapid and precise amplification of DNA sequences. By using primers that contain a specific nucleotide change, researchers can use PCR to create copies of an entire gene that incorporate a targeted mutation. This method has made it much simpler and faster to engineer enzymes with specific amino acid changes for research and industrial applications.

251. (A) 1000 substrate molecules per second per enzyme active site
A turnover number of 1000 per second indicates that each individual active site on an enzyme molecule is capable of converting 1000 substrate molecules into product every second under saturating conditions. This parameter is a fundamental measure of the enzyme's maximal catalytic capacity. It allows scientists to compare the speeds of different enzymes regardless of the total concentration of enzyme used in an experimental assay.

252. (A) Competition for solvation water between the added salt and the protein
Salting out occurs because added salt ions have a very high affinity for water molecules, effectively stripping away the layer of hydration that normally keeps proteins soluble. As the salt concentration rises, more water is diverted to solvate the salt ions, leaving the protein molecules with less water to interact with. This forces the hydrophobic surfaces of the proteins to clump together, leading to their aggregation and precipitation.

253. (A) Measuring a product's appearance (e.g., absorbance change) in real-time
A continuous monitoring assay is a method of measuring enzyme activity where the reaction is followed as it happens, typically by observing a change in light absorbance. For example, if a product absorbs light at a specific wavelength that the substrate does not, a spectrophotometer can record the increase in absorbance over time. This provides a direct and detailed view of the reaction's initial velocity.

254. (A) Bradford assay
The Bradford assay is one of the most common colorimetric methods used in biochemistry to determine the total concentration of protein

in a sample. It relies on the binding of a dye, Coomassie Brilliant Blue, to the proteins, which causes the dye's color to shift from reddish-brown to bright blue. The intensity of the blue color is proportional to the amount of protein, allowing for easy quantification.

255. (B) II, III, IV, and V
Most water-soluble vitamins serve as essential cofactors for various metabolic processes. Vitamin C acts as a vital antioxidant and is needed for collagen synthesis. Folic acid is indispensable for the production of DNA precursors, and pyridoxine is the key cofactor for enzymes involved in amino acid metabolism. Thiamine deficiency leads to beriberi, highlighting its central role in energy production. Biotin, however, does not require intrinsic factor.

256. (A) Vitamin K
While vitamin K is an essential fat-soluble nutrient that must be obtained from the diet, particularly from leafy green vegetables, humans also benefit from another source. Specialized bacteria living in the large intestine are capable of synthesizing vitamin K2, which can be absorbed and used by the body. This dual source helps to ensure that most healthy individuals maintain sufficient levels for normal blood clotting and bone health.

257. (C) Inability to hydroxylate proline and lysine in collagen
The primary biochemical failure in scurvy is the disruption of collagen synthesis due to a lack of vitamin C. This vitamin is a required co-substrate for the enzymes that add hydroxyl groups to the amino acids proline and lysine within the collagen protein. Without these modifications, the collagen fibers cannot form the stable triple-helix structure needed to provide strength to blood vessels, skin, and other connective tissues.

258. (A) NAD+/NADP+
Pellagra is a disease caused by a severe deficiency of niacin, which is the essential precursor for the synthesis of the coenzymes NAD and NADP. These molecules are fundamental for almost all oxidation-reduction reactions in the body, including those in glycolysis and the citric acid cycle. Without sufficient niacin, cellular respiration and energy production are severely compromised, leading to the systemic failure and characteristic symptoms associated with the disease.

259. (A) Thiamine
Wernicke-Korsakoff syndrome is a severe neurological condition most often seen in individuals with chronic alcoholism who also suffer from a severe deficiency of thiamine. Alcohol interferes with the absorption and activation of thiamine, which is critical for energy metabolism in the brain. The resulting lack of thiamine leads to brain lesions, memory loss, and coordination problems, representing a severe manifestation of the metabolic importance of this vitamin.

260. (A) Vitamin D
Vitamin D is unique because it can be synthesized endogenously when the skin is exposed to ultraviolet B radiation from sunlight. This radiation triggers a photochemical reaction that converts 7-dehydrocholesterol into previtamin D3, which then spontaneously rearranges into cholecalciferol. This ability to produce the vitamin through light exposure is essential for maintaining calcium balance, especially for people who have limited dietary intake of this fat-soluble nutrient.

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261. (A) 11-cis-retinal
The visual cycle begins when the protein opsin binds to a specific isomer of vitamin A known as 11-cis-retinal, forming the pigment rhodopsin. This molecule is extremely sensitive to light; when a photon strikes it, the 11-cis-retinal is instantly converted into the all-trans form. This structural change triggers a nerve impulse that is sent to the brain, allowing us to see. The vitamin must then be recycled back to its cis form.

262. (A) Adenylate cyclase
Glucagon signaling is initiated when the hormone binds to its G-protein coupled receptor on the cell surface. This binding causes the alpha subunit of the G-protein to exchange GDP for GTP and dissociate. The activated G-alpha subunit then moves along the membrane to find and activate the enzyme adenylate cyclase. This enzyme then produces the second messenger cAMP, which continues the signal cascade to mobilize glucose from the liver.

263. (A) Receptor tyrosine kinase
The insulin receptor belongs to a class of signaling proteins known as receptor tyrosine

kinases. When insulin binds to the extracellular part of the receptor, it triggers the two internal parts to phosphorylate each other on specific tyrosine residues. This autophosphorylation creates binding sites for other signaling proteins, initiating a complex intracellular pathway that eventually leads to increased glucose uptake and the regulation of fat and protein metabolism.

264. (A) Binding to nuclear receptors and regulating gene expression
Thyroid hormones T3 and T4 are lipid-soluble and act by entering the nucleus of target cells to bind to specific thyroid hormone receptors. These receptors are already bound to the DNA at specific sites. When the hormone attaches, it causes the receptor to change shape and activate or repress the transcription of nearby genes. This genomic action allows thyroid hormones to coordinate long-term changes in the body's metabolic rate and development.

265. (B) The anterior synthesizes hormones; the posterior only stores them
The pituitary gland is divided into two parts with fundamentally different origins and functions. The anterior pituitary is a true gland that synthesizes and secretes several of its own hormones in response to signals from the hypothalamus. In contrast, the posterior pituitary is an extension of the nervous system. It does not produce its own hormones but instead stores and releases hormones that were synthesized in the hypothalamus.

266. (A) Stimulate osteoclast activity to resorb bone and release calcium
Parathyroid hormone is the primary regulator of blood calcium levels. When calcium is low, PTH is released and acts on the bone to stimulate the activity of osteoclasts. These specialized cells break down the mineralized bone matrix, releasing stored calcium and phosphate into the bloodstream. This rapid mobilization of calcium from the skeletal reservoir is an essential mechanism for maintaining the body's mineral balance and supporting nervous system function.

267. (A) ACTH
The production of cortisol by the adrenal cortex is controlled by a hormonal cascade known as the HPA axis. In response to stress, the hypothalamus secretes CRH, which stimulates the anterior pituitary to release adrenocorticotropic hormone. ACTH then travels through the blood to the adrenal glands, where it binds to specific receptors and triggers the rapid synthesis and secretion of cortisol. This tightly regulated pathway ensures a coordinated response to physical stress.

268. (A) Anti-inflammatory and immunosuppressive effects
Glucocorticoids, such as cortisol and its synthetic analogs like prednisone, are among the most commonly used drugs for treating inflammatory and autoimmune conditions. They function by entering cells and regulating the expression of genes involved in the immune response, ultimately reducing the production of inflammatory signaling molecules. This potent ability to suppress inflammation and immune activity makes them invaluable for managing asthma, rheumatoid arthritis, and many other systemic disorders.

269. (A) Pineal gland
Melatonin is a hormone synthesized from the amino acid tryptophan and secreted by the pineal gland, a small endocrine organ located deep in the brain. Its production is tightly linked to the light-dark cycle, with levels rising at night and falling during the day. By signaling the time of day to the rest of the body, melatonin helps to regulate the circadian rhythm and coordinate the sleep-wake cycle.

270. (A) I, III, IV, II
Steroid hormone signaling follows a precise sequence of events. First, the lipid-soluble hormone diffuses across the cell membrane and binds to its specific receptor in the cytoplasm or nucleus. The resulting hormone-receptor complex then translocates to the nucleus if it is not already there. Once inside, it binds to DNA at specific regulatory sequences and alters the transcription of target genes, leading to a physiological response.

271. (D) The inhibition of lateral buds by auxin produced in the shoot apex
Apical dominance is a classic plant growth phenomenon where the main, central stem of the plant grows more strongly than the side branches. This is primarily caused by auxin that is produced in the actively growing shoot tip and transported downward. This downward flow of auxin acts to keep the lateral buds in a dormant

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state, ensuring that the plant allocates most of its resources to growing upward toward light.

272. (A) Shoot apical meristems and young leaves
The primary sites of auxin biosynthesis in plants are the shoot apical meristems and the youngest developing leaves. These regions are characterized by high metabolic activity and rapid cell division. From these apical sites, auxin is transported downward through the rest of the plant to regulate various developmental processes. This centralized production and directional transport are essential for establishing the plant's overall body plan and coordinating its growth.

273. (A) DELLA
Gibberellin signaling relies on a specialized mechanism that involves the removal of repressor proteins known as DELLA proteins. In the absence of gibberellin, these proteins bind to and inhibit the transcription factors that promote growth. When gibberellin levels rise, the hormone binds to its receptor, which then targets the DELLA proteins for degradation. This release from inhibition allows the plant to initiate stem elongation, seed germination, and other growth-related processes.

274. (A) Cytokinin
Cytokinins use a signaling pathway that is very similar to the two-component systems found in bacteria. This pathway involves a membrane-bound receptor that, upon binding the hormone, transfers a phosphate group to an internal signaling protein. This protein then moves into the nucleus to activate the transcription of cytokinin-responsive genes. This sophisticated system allows the plant to rapidly sense and respond to changes in cytokinin levels, coordinating cell division and development.

275. (B) Ethylene
The ripening of climacteric fruits, such as bananas, tomatoes, and apples, is triggered and coordinated by a massive increase in the production of ethylene gas. This surge in ethylene acts as a master switch that turns on various genes responsible for changes in color, texture, and flavor. Because ethylene is a gas, it can also spread to neighboring fruits, helping to synchronize the ripening process across an entire cluster or harvest.

276. (B) Stimulating rapid stomatal closure
When plants encounter drought or other water-related stress, they rapidly increase the production of abscisic acid. This hormone travels to the leaves and signals the guard cells surrounding the stomata to close. By shutting these pores, the plant significantly reduces the amount of water lost through transpiration, which is a critical survival strategy for maintaining internal hydration during periods when soil water is scarce or unavailable.

277. (A) Salicylic acid and reactive oxygen species
The hypersensitive response is a form of programmed cell death that occurs at the site of a pathogen infection to prevent the spread of the disease. This localized response is triggered by a rapid burst of salicylic acid and reactive oxygen species, which work together to kill both the infected plant cells and the invading microbes. This localized "suicide" is a highly effective part of the plant's overall immune system.

278. (A) Brassinosteroids
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Brassinosteroids are a class of steroid hormones that are absolutely essential for a wide range of plant developmental processes. They are involved in photomorphogenesis, which is how plants grow in response to light, and are critical for the expansion and division of cells. Without these hormones, plants cannot develop their normal architecture and often show severe growth defects, highlighting the fundamental importance of brassinosteroids in coordinating complex plant life.

279. (A) Strigolactones
Mycorrhizal fungi form a vital symbiotic relationship with the roots of many plant species, helping them to absorb nutrients from the soil. These fungi find and identify their host plants by detecting specific chemical signals called strigolactones that are exuded from the roots into the soil. This chemical communication is essential for the establishment of the symbiosis, allowing the fungus and the plant to find each other in the complex environment.

280. (A) P-2, Q-3, R-4, S-1
Plants use a diverse array of chemical compounds to regulate their growth and defense. Salicylic acid is a simple phenolic molecule, while brassinosteroids are a type of steroid hormone. Strigolactones are derived from carotenoid

pigments and possess a characteristic lactone structure. Jasmonic acid is a lipid-derived compound that belongs to the cyclopentanone family. Each of these bioregulators plays a unique and essential role in plant biology.

281. (A) Purity
Specific activity is the best indicator of how pure an enzyme sample is during a purification process. It is defined as the amount of enzyme activity per unit mass of total protein. As more non-target proteins are removed during each step, the specific activity of the remaining sample will increase. This value allows researchers to track their progress and determine whether additional purification steps are needed to reach the desired level.

282. (B) First-order
In chemical and enzyme kinetics, a reaction is described as first-order when its rate is directly proportional to the concentration of a single reactant. For an enzymatic reaction, this typically occurs at low substrate concentrations, well below the Michaelis constant. In this range, every increase in the amount of substrate leads to a corresponding and predictable increase in the speed of the reaction, as many active sites are still available.

283. (A) The rate of ES complex formation equals the rate of its breakdown
The steady-state assumption is a fundamental concept used to simplify the mathematical analysis of enzyme kinetics. It posits that after an initial very brief period, the concentration of the enzyme-substrate complex remains nearly constant throughout the reaction. This means that the rate at which the complex is created from free enzyme and substrate is equal to the rate at which it is converted into products or reverts to reactants.

284. (B) Uncompetitive lowers both Vmax and Km; non-competitive lowers only Vmax
Uncompetitive and non-competitive inhibitors can be distinguished by their different effects on the Michaelis-Menten kinetic parameters. Uncompetitive inhibitors bind only to the enzyme-substrate complex, leading to a decrease in both the maximum velocity and the Michaelis constant. In contrast, pure non-competitive inhibitors bind to a separate site with equal affinity for both the free enzyme and the complex, resulting in a lower $V_{\max}$ while the K_m remains unchanged.

285. (A) Both A and R are true and R is the correct explanation of A.
Plant roots grow downward in response to gravity through a process called positive gravitropism. This is mediated by the redistribution of auxin to the lower side of the root tip. Because roots are highly sensitive to auxin, these high concentrations actually inhibit cell elongation on the bottom side while the top side continues to grow normally. This uneven growth rate causes the root to bend downward into the soil.

286. (A) Retain functionality and stability at elevated processing temperatures
Extremozymes from thermophilic organisms are highly valued in industrial applications because they are naturally evolved to be extremely stable and active at high temperatures. Many industrial processes, such as the breakdown of starch or the synthesis of chemicals, are more efficient when performed at elevated temperatures to increase solubility and reaction rates. These thermophilic enzymes can withstand these harsh conditions without denaturing, providing a robust and reliable catalyst.

287. (A) A kcat/Km ratio approaching the diffusion-controlled limit
The ultimate measure of an enzyme's catalytic performance is its catalytic efficiency, which is the ratio of its turnover number to its Michaelis constant. An enzyme is considered to have reached "catalytic perfection" when this ratio is between ten to the eighth and ten to the ninth. At this point, the reaction is so fast that its rate is limited only by how quickly the substrate can move to the enzyme's active site.

288. (C) Regulatory site distinct from the active site
Allosteric modulators are specialized molecules that regulate enzyme activity by binding to a regulatory site, also known as an allosteric site, which is physically separate from the catalytic active site. This binding causes a conformational change in the enzyme that either increases or decreases its affinity for the substrate. This allows the cell to fine-tune metabolic processes through sensitive and reversible control mechanisms that do not compete with the substrate.

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289. (A) Tertiary structure
The tertiary structure of a protein refers to its complete three-dimensional folding, which is primarily driven by various interactions between the side chains of amino acids. This complex folding is what creates the precisely shaped and chemically unique active site of an enzyme. Any disruption to this level of structure will likely cause the active site to collapse or change shape, resulting in a loss of the enzyme's specific catalytic function.

290. (C) I and III
Salicylic acid and strigolactones are essential bioregulators that coordinate different aspects of plant life. Salicylic acid is the primary signal for systemic acquired resistance, helping the plant defend itself against pathogens. Strigolactones, meanwhile, play a critical role in controlling plant architecture by suppressing the branching of the shoot system. Brassinosteroids, however, are synthesized through the isoprenoid pathway rather than directly from carotenoids, making the second statement incorrect.

291. (A) It is devoid of its necessary non-protein cofactor
An apoenzyme is the purely proteinaceous part of an enzyme that requires a non-protein cofactor to be functionally active. Without this essential cofactor, the protein lacks the necessary chemical groups or structural features to perform catalysis. The term holoenzyme refers to the complete, active complex formed when the apoenzyme and its cofactor are bound together, representing the biologically functional unit of the enzyme within the cell.

292. (A) Remains unchanged
In pure non-competitive inhibition, the inhibitor binds to a regulatory site with equal affinity for both the free enzyme and the enzyme-substrate complex. This binding reduces the enzyme's turnover rate but does not affect how well the substrate binds to the active site. Consequently, on a Lineweaver-Burk plot, the lines representing the reaction with and without the inhibitor will cross the horizontal x-axis at the same point, as K_m remains unchanged.

293. (A) Disrupt the crucial hydrophobic interactions required for the 3D structure
Enzymes are held in their functional three-dimensional shapes by a delicate balance of weak interactions, particularly hydrophobic interactions between non-polar amino acids in the protein's core. Organic solvents are much less polar than water and can penetrate these regions, disrupting the hydrophobic forces that stabilize the protein. This leads to the unfolding, or denaturation, of the enzyme, causing it to lose its active site and its catalytic ability.

294. (A) Bleeding gums and poor wound healing
Scurvy is the classic result of a severe deficiency in vitamin C, which is essential for the stable formation of collagen fibers. Without vitamin C, the connective tissues throughout the body become weak and fragile. This leads to the hallmark symptoms of the disease, including bleeding gums, loose teeth, internal bruising, and wounds that do not heal properly. These symptoms reflect the fundamental role of collagen in maintaining the integrity of tissues.

295. (A) I only
Glucagon is a hormone produced by the pancreas that acts primarily to increase the concentration of glucose in the blood, particularly during fasting. Therefore, the statement claiming it decreases blood glucose is incorrect. Insulin, cortisol, and aldosterone are correctly paired with their functions: insulin promotes fat storage, cortisol increases the synthesis of new glucose, and aldosterone helps the kidneys retain sodium to regulate blood pressure and volume.

296. (A) Electron transport mediated by a reversible iron redox state
Cytochromes are a group of specialized proteins that contain a heme group with a central iron ion. They function as essential electron carriers in the mitochondria and chloroplasts, participating in the respiratory and photosynthetic electron transport chains. The iron ion within the heme can easily cycle between its reduced and oxidized states, allowing the cytochrome to accept and donate electrons with high efficiency to drive energy production.

297. (A) Shifts the line parallel to the uninhibited line
Uncompetitive inhibition produces a very distinctive pattern on a Lineweaver-Burk plot. Because the inhibitor reduces both the maximum velocity and the Michaelis constant by the same factor, the slope of the line, which is K_m over $V_{\max}$, remains unchanged. This results in a series of parallel lines as the inhibitor concentration is

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228. (B) Auxin and Cytokinin
The degree of shoot branching in plants is primarily determined by the balance between two antagonistic hormones: auxin and cytokinin. Auxin produced in the shoot tip travels downward to inhibit the growth of lateral buds, maintaining apical dominance. In contrast, cytokinins produced in the roots move upward and promote the growth of these same buds. The interaction between these two signals allows the plant to adjust its shape.

229. (D) Auxin signaling
Recent research has shown that strigolactones act as a third hormonal signal that helps to inhibit shoot branching, working in conjunction with auxin. Specifically, strigolactones are thought to act downstream of auxin signaling to suppress the development of lateral buds. By integrating signals from both the shoot and root systems, strigolactones allow the plant to regulate its branching architecture in response to nutrient availability in the soil.

230. (B) Is unreactive until acted upon by the enzyme's catalytic mechanism
Suicide inhibitors are a unique class of irreversible inhibitors that are designed to be chemically inert when they first enter the active site. However, during the catalytic process, the enzyme itself converts the inhibitor into a highly reactive species. This reactive intermediate then forms a stable covalent bond with a nearby residue, permanently inactivating the enzyme. This "self-destruction" mechanism makes them highly specific and effective drugs.

231. (C) Optimum temperature
Every enzyme has a specific optimum temperature at which its catalytic activity is at its highest point. At temperatures below this peak, the rate of reaction is limited by the lower kinetic energy of the molecules. Above the optimum, the increased thermal energy begins to disrupt the weak interactions maintaining the enzyme's structure, leading to rapid denaturation and a sharp decline in activity.

232. (C) Isoenzymes
Hexokinase and glucokinase are classic examples of isoenzymes because they both catalyze the same initial step of glucose metabolism but are different proteins with distinct properties. Hexokinase is found in most tissues and has a high affinity for glucose, while glucokinase is primarily in the liver and has a much lower affinity. These differences allow the body to manage glucose levels effectively under varying physiological conditions.

233. (D) Cooperative binding among multiple subunits
The characteristic sigmoidal shape of the kinetic curve for allosteric enzymes is a direct reflection of cooperativity between their multiple subunits. When a substrate molecule binds to one subunit, it induces a structural change that makes it easier for subsequent substrate molecules to bind to the other subunits. This results in a rapid increase in the reaction rate over a narrow range of substrate concentrations, providing sensitive metabolic control.

234. (A) The Y-axis
In competitive inhibition, the inhibitor binds only to the free enzyme and can be fully displaced if the substrate concentration is high enough. As a result, the maximum reaction velocity is not affected by the presence of the inhibitor. This is visualized on a Lineweaver-Burk plot as a series of lines that all cross the vertical y-axis at the same point, which represents the reciprocal of $V_{\max}$.

235. (C) High-energy molecular configuration attained during catalysis
Transition state theory suggests that enzymes achieve their remarkable catalytic power by binding more tightly to the transition state than to the original substrate. Therefore, molecules designed to mimic this high-energy transition state configuration should be extremely potent inhibitors. These transition state analogs can bind to the active site with much higher affinity than the substrate, making them ideal candidates for the development of new pharmaceutical agents and research tools.

236. (B) Glycopeptide transpeptidase
Penicillin is a well-known antibiotic that works by irreversibly inhibiting glycopeptide transpeptidase, an enzyme essential for building the bacterial cell wall. The structure of penicillin mimics the natural substrate of the enzyme, allowing it to enter the active site and form a stable covalent bond with a serine residue. By preventing the cross-linking of the cell wall, penicillin causes the bacteria to burst and die.

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CHAPTER 04
Molecular Biology

2004

1. Which pyrimidine base is unique to RNA and structurally lacks a methyl group at the 5-position compared to its DNA counterpart?
(A) Uracil
(B) Cytosine
(C) Thymine
(D) Adenine

2006

2. According to Chargaff's rules for double-stranded DNA, which of the following molar ratios is expected to equal 1?
(A) $\frac{A}{G}$
(B) $\frac{A+T}{G+C}$
(C) $\frac{A+G}{C+T}$
(D) $\frac{C}{T}$

2006

3. Which linkage connects the 3'-hydroxyl group of one nucleotide to the 5'-phosphate group of the next nucleotide in a nucleic acid polymer?
(A) Phosphodiester bond
(B) Glycosidic bond
(C) Hydrogen bond
(D) Peptide bond

2003

4. Among the structural variants of DNA, which form is characterized by a left-handed helical rotation and a zig-zag sugar-phosphate backbone?
(A) A-form
(B) B-form
(C) C-form
(D) Z-form

2004

5. The basic nucleoside unit consists of a nitrogenous base attached to a pentose sugar. Which specific atom of a pyrimidine base connects to the 1'-carbon of the sugar?
(A) N-3
(B) N-1
(C) N-9
(D) C-5

2024

6. At physiological pH, the phosphate groups in the DNA backbone carry a net charge. What is this charge?
(A) Positive
(B) Neutral
(C) Negative
(D) Variable depending on the base

2002

7. Which environmental condition is most likely to induce the transition of B-DNA to the A-DNA conformation in vitro?
(A) High humidity
(B) Low salt concentration
(C) High temperature
(D) Dehydration

2019

8. In B-form DNA, approximately how many base pairs are present per complete 360-degree helical turn?
(A) 9.5
(B) 10.5
(C) 11.0
(D) 12.0

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2003

9. Identify the INCORRECT statement regarding DNA denaturation.
(A) Heating DNA increases its UV absorbance at 260 nm.
(B) GC-rich DNA has a lower melting temperature than AT-rich DNA.
(C) Hydrogen bonds break during the denaturation process.
(D) Formamide lowers the melting temperature of DNA.

2009

10. Read the following statements and select the correct option.
Assertion (A) : Z-DNA formation is favored by alternating purine-pyrimidine sequences, such as poly(dG-dC).

Q. FEN1
R. Pol γ
S. PCNA

List II : (Eukaryotic Counterpart/Function)

1. Mitochondrial replication
2. Lagging strand synthesis
3. Sliding clamp
4. Flap endonuclease for primer removal

(A) P-2, Q-4, R-1, S-3
(B) P-4, Q-2, R-3, S-1
(C) P-1, Q-3, R-2, S-4
(D) P-2, Q-1, R-4, S-3

2015

56. Which structural formation is created when the single-stranded 3' overhang of a telomere loops back and invades the double-stranded region to protect the end?
(A) T-loop
(B) D-loop
(C) Holiday junction
(D) R-loop

2017

57. The gradual shortening of telomeres with each cell division in somatic cells ultimately leads to a state of irreversible growth arrest known as:
(A) Apoptosis
(B) Replicative senescence
(C) Necrosis
(D) Transformation

2010

58. Eukaryotic replication origins are marked by a multiprotein complex that binds to the DNA throughout the cell cycle. This complex is called the:
(A) Pre-replication complex (pre-RC)
(B) Origin recognition complex (ORC)
(C) Replisome
(D) Primosome

2021

59. Which of the following best describes the difference in the rate of replication fork progression between prokaryotes and eukaryotes?
(A) It is slower in eukaryotes due to chromatin structure.
(B) It is much faster in eukaryotes due to larger genome size.
(C) It is identical in both domains.
(D) It varies randomly depending on the chromosome.

2016

60. Consider the following sequence of eukaryotic replication initiation events:
I. ORC binding
II. DNA unwinding by helicase
III. Cdc6 and Cdt1 recruitment
IV. MCM helicase loading
Which of the following is the correct chronological order?
(A) I, II, III, IV
(B) I, III, IV, II
(C) III, I, IV, II
(D) IV, I, III, II

2021

61. In prokaryotes, which subunit of RNA polymerase is strictly required for the specific recognition of promoter sequences?
(A) Alpha
(B) Beta
(C) Beta prime
(D) Sigma

2021

62. The consensus sequence located at approximately -10 upstream of the transcription start site in E. coli is known as the:
(A) TATA box
(B) CAAT box
(C) Pribnow box
(D) GC box

2017

63. Which step of transcription involves the dissociation of the sigma factor from the RNA polymerase holoenzyme?
(A) Promoter binding
(B) Elongation
(C) Initiation
(D) Termination

2021

64. In eukaryotes, which transcription factor contains the TATA-binding protein (TBP) critical for RNA Polymerase II initiation?
(A) TFIIA
(B) TFIIB
(C) TFIIH
(D) TFIID

2018

65. Enhancers are cis-acting DNA regulatory elements. Which statement most accurately describes their function?
(A) They can increase transcription levels from a great distance.

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2018

21. Which specific region of the tRNA molecule covalently attaches to its corresponding amino acid?
(A) Anticodon loop
(B) 3'-CCA terminus
(C) D loop
(D) TψC loop

2021

22. In prokaryotes, what is the sedimentation coefficient of the intact functional ribosome?
(A) 60S
(B) 70S
(C) 80S
(D) 90S

2018

23. Polycistronic mRNA, which carries the coding information for multiple proteins, is predominantly found in which organisms?
(A) Mammals
(B) Fungi
(C) Plants
(D) Bacteria

2021

24. Which unusual base is commonly found in the T ψC loop of transfer RNA?
(A) Pseudouridine
(B) Inosine
(C) Dihydrouridine
(D) 5-Methylcytosine

2022

25. The fundamental repeating unit of chromatin, consisting of DNA wrapped around a histone octamer, is called a:
(A) Centrosome
(B) Nucleosome
(C) Telomere
(D) Chromatosome

2019

26. Which of the following is NOT a core histone protein found in the nucleosome octamer?
(A) H2A
(B) H1
(C) H2B
(D) H4

2023

27. What is the approximate length of DNA that wraps around a single nucleosome core particle?
(A) 50 base pairs
(B) 100 base pairs
(C) 146 base pairs
(D) 200 base pairs

2013

28. Which enzyme is responsible for relaxing supercoiled DNA by creating transient single-strand breaks?
(A) DNA Helicase
(B) Type II Topoisomerase
(C) Type I Topoisomerase
(D) DNA Ligase

2003

29. The topological state of circular DNA is defined by the equation $L = T + W$. What does 'W' represent in this context?
(A) Linking number
(B) Twist
(C) Wavelength
(D) Writhe

2011

30. Consider the following statements regarding DNA supercoiling:
I. Most naturally occurring DNA is negatively supercoiled.
II. DNA gyrase introduces positive supercoils in bacteria.
III. Positive supercoiling over-winds the DNA double helix.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) I and III
(C) II
(D) III

2010

31. What is the function of the H1 histone in chromatin organization?
(A) Forms the structural core of the histone octamer
(B) Binds to linker DNA to stabilize higher-order structures
(C) Catalyzes the process of DNA unwinding and relaxation
(D) Acetylates other histones via enzymatic modification

2006

32. In the hierarchical model of chromatin packaging, the 10-nm fiber is folded into a thicker structure with a diameter of approximately:
(A) 20 nm
(B) 30 nm
(C) 100 nm
(D) 300 nm

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Reason (R) : The purines in Z-DNA adopt a syn conformation while pyrimidines adopt an anti conformation.

(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2009

11. Which force is primarily responsible for the vertical stacking interactions between adjacent base pairs in the DNA double helix?
(A) Hydrophobic effects and van der Waals forces
(B) Electrostatic ionic interactions between groups
(C) Covalent bonds within the sugar-phosphate chain
(D) Intramolecular disulfide bridges between residues

2014

12. What structural feature distinguishes a ribonucleotide from a deoxyribonucleotide?
(A) The presence of a 3'-hydroxyl group
(B) The presence of a 5'-phosphate group
(C) The presence of a 2'-hydroxyl group
(D) The lack of a 2'-hydroxyl group

2018

13. Which cellular RNA molecule serves as the structural and catalytic core of the ribosome?
(A) mRNA
(B) tRNA
(C) snRNA
(D) rRNA

2021

14. Which specific type of small RNA is primarily involved in the regulation of gene expression by inducing mRNA degradation or translational repression?
(A) snRNA
(B) snoRNA
(C) miRNA
(D) tRNA

2012

15. The secondary structure of tRNA is commonly described as having which specific shape?
(A) Hairpin loop
(B) Cloverleaf
(C) L-shape
(D) Linear strand

2018

16. In eukaryotic cells, which mature RNA typically contains a 5'-7-methylguanosine cap and a 3'-poly(A) tail?
(A) rRNA
(B) tRNA
(C) snRNA
(D) mRNA

2010

17. Which small nuclear RNA (snRNA) binds to the 5' splice site of pre-mRNA during the early stages of spliceosome assembly?
(A) U1
(B) U2
(C) U4
(D) U6

2024

18. What is the primary function of small nucleolar RNAs (snoRNAs) in the cell?
(A) Splicing of pre-mRNA transcripts
(B) Transporting specific amino acids
(C) Chemical modification of rRNAs
(D) Initiating genomic transcription

NODIA

2007

19. Identify the correct pair regarding RNA polymerase and its primary transcript in eukaryotes.
(A) RNA Polymerase II - pre-mRNA
(B) RNA Polymerase I - mRNA
(C) RNA Polymerase II - tRNA
(D) RNA Polymerase III - 5.8S rRNA

2006

20. Match the RNA types in List I with their functions in List II.

List I : (RNA Type)
P. mRNA
Q. tRNA
R. rRNA
S. miRNA

List II : (Function/Characteristic)
1. Translates codons to amino acids
2. Catalyzes peptide bond formation
3. Template for protein synthesis
4. Endogenous gene silencing

(A) P-3, Q-1, R-2, S-4
(B) P-3, Q-2, R-1, S-4
(C) P-1, Q-3, R-4, S-2
(D) P-2, Q-1, R-3, S-4

2005

45. Read the following statements and select the correct option.
Assertion (A) : DNA replication is strictly a 5' to 3' process.
Reason (R) : DNA polymerases can only add incoming dNTPs to the free 3'-OH group of the growing chain.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2007

46. Which DNA polymerase is primarily responsible for gap filling and DNA repair in E. coli?
(A) DNA Polymerase II
(B) DNA Polymerase III
(C) DNA Polymerase I
(D) DNA Polymerase V

2017

47. The proofreading ability of replicative DNA polymerases is mediated by which intrinsic enzymatic activity?
(A) 5' to 3' exonuclease
(B) 3' to 5' exonuclease
(C) 5' to 3' endonuclease
(D) 3' to 5' endonuclease

2021

48. In eukaryotic DNA replication, which polymerase complex is primarily responsible for initiating synthesis by laying down the RNA-DNA primer?
(A) Polymerase delta
(B) Polymerase epsilon
(C) Polymerase gamma
(D) Polymerase alpha

2016

49. Telomeres are repetitive DNA sequences located at the ends of linear chromosomes. What is their primary function?
(A) To protect chromosomal ends from degradation and fusion
(B) To initiate the start of genomic DNA replication
(C) To code for essential regulatory protein products
(D) To serve as attachment points for spindle fibers

2011

50. Consider the following statements concerning telomerase:
I. It is a ribonucleoprotein.
II. It extends the 3' end of the leading strand template.
III. It uses a built-in RNA template.
IV. It exhibits reverse transcriptase activity.
V. It is highly active in most normal somatic cells.
Which of the above statements are correct?
(A) I, II and IV
(B) I, III and V
(C) II, IV and V
(D) I, III and IV

2005

51. The "end-replication problem" uniquely affects which type of genomic architecture?
(A) Linear eukaryotic chromosomes
(B) Circular bacterial chromosomes
(C) Circular mitochondrial plasmids
(D) Viral single-stranded circular DNA

2025

52. Telomerase enzyme synthesizes DNA using an RNA template. This mechanism makes telomerase a specialized type of:
(A) RNA-dependent RNA polymerase
(B) DNA-dependent RNA polymerase
(C) DNA-dependent DNA polymerase
(D) RNA-dependent DNA polymerase

2023

53. In most vertebrates, including humans, the highly conserved hexameric sequence repeated at telomeres is:
(A) TTGGCC
(B) TTAGGG
(C) AATCCC
(D) GGCATC

2015

54. Prokaryotic chromosomes generally do not require telomerase. What is the most relevant biological reason for this?
(A) They possess specialized ligases.
(B) Their DNA is composed of RNA.
(C) Their chromosomes are circular.
(D) Their replication is bidirectional.

2019

55. Match the replication components in List I with their counterparts or functions in List II.
List I : (Replication Component)
P. Pol δ

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(D) UTP

2007

100. Consider the following statements concerning translation elongation:

I. EF-Tu delivers aminoacyl-tRNA to the A site.

II. Peptide bond formation is catalyzed by rRNA.

III. Translocation shifts the uncharged tRNA to the E site.

IV. Translocation is powered by ATP hydrolysis.

Which of the above statement(s) is/are correct?

(A) I, II and III

(B) I, II and IV

(C) II, III and IV

(D) I, III and IV

2003

101. The catalytic activity responsible for forming the peptide bond during translation is inherently located in:

(A) The small ribosomal subunit proteins

(B) The large ribosomal subunit RNA

(C) Transfer RNA molecules

(D) Translation elongation factors

2002

102. In eukaryotic translation initiation, the complex generally scans the mRNA starting from the 5' cap to locate the start codon embedded within which consensus sequence?

(A) Shine-Dalgarno sequence

(B) Kozak consensus sequence

(C) Initiator element (Inr)

(D) Poly(A) signal

2007

103. Which site on the ribosome accepts the incoming aminoacyl-tRNA during the elongation phase?

(A) P site

(B) E site

(C) S site

(D) A site

2016

104. Which translation termination factor in prokaryotes recognizes the stop codons UAA and UAG?

(A) RF1

(B) RF2

(C) RF3

(D) eRF1

NODIA

2007

105. Read the following statements and select the correct option.

Assertion (A) : In bacteria, the first amino acid incorporated into a polypeptide is N-formylmethionine.

Reason (R) : The formyl group protects the amino terminus from rapid proteolytic degradation during synthesis.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is not the correct explanation of A.

(C) A is true but R is false.

(D) A is false but R is true.

2013

106. During the translocation step of translation, the ribosome moves exactly how many nucleotides along the mRNA?

(A) One

(B) Two

(C) Three

(D) Four

2008

107. Which elongation factor is crucial for ribosomal translocation in prokaryotes?

(A) EF-G

(B) EF-Tu

(C) EF-Ts

(D) IF-2

2012

108. Antibiotics often inhibit bacterial translation without affecting eukaryotes. Which antibiotic specifically inhibits peptidyl transferase activity by binding to the 50S subunit?

(A) Tetracycline

(B) Streptomycin

(C) Chloramphenicol

(D) Puromycin

2015

109. Post-translational modifications increase the functional diversity of the proteome. Which modification involves the addition of a lipid anchor to a protein?

(A) Phosphorylation

(B) Glycosylation

(C) Ubiquitination

(D) Prenylation

2003

110. Consider the following statements regarding ubiquitination:

(B) They must be located immediately adjacent to the promoter.
(C) They are transcribed into structural RNA molecules.
(D) They inhibit the binding of the RNA polymerase enzyme.

2009

66. The intrinsic (rho-independent) termination of transcription in prokaryotes relies on the formation of which RNA structure?
(A) An A-U rich duplex
(B) A lariat structure
(C) A GC-rich hairpin loop followed by a poly-U tract
(D) A cruciform loop

2013

67. Which general transcription factor possesses both helicase and kinase activities essential for promoter clearance in eukaryotes?
(A) TFIIH
(B) TFIID
(C) TFIIE
(D) TFIIF

2003

68. The fungal toxin alpha-amanitin is a potent inhibitor of transcription. Which eukaryotic RNA polymerase is most sensitive to it?
(A) RNA Polymerase I
(B) RNA Polymerase III
(C) Mitochondrial RNA Polymerase
(D) RNA Polymerase II

2008

69. In contrast to prokaryotic transcription, eukaryotic transcription generally requires:
(A) Coupling with translation
(B) Chromatin remodeling
(C) A single highly conserved sigma factor
(D) Operon structures

2021

70. Read the following statements and select the correct option.
Assertion (A) : Prokaryotic transcription and translation can occur simultaneously.
Reason (R) : Prokaryotes lack a nuclear membrane, allowing ribosomes direct access to nascent mRNA.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2008

71. Eukaryotic promoters often contain a CAAT box. What is the general location of this element relative to the transcription start site?
(A) -10 to -20
(B) -25 to -30
(C) -70 to -80
(D) +10 to +20

2025

72. Which transcription factor recruits RNA Polymerase II to the eukaryotic pre-inititation complex?
(A) TFIIF
(B) TFIIA
(C) TFIIB
(D) TFIIE

2025

73. The 5' cap added to eukaryotic pre-mRNA consists of which modified nucleotide?
(A) 7-methyladenosine
(B) 7-methylguanosine
(C) 5-methylcytosine
(D) N6-methyladenosine

2008

74. Which specialized linkage connects the 5' cap to the first nucleotide of the pre-mRNA transcript?
(A) 3',5'-phosphodiester bond
(B) 5',5'-triphosphate linkage
(C) 2',5'-phosphodiester bond
(D) Glycosidic linkage

2021

75. Read the following statements and select the correct option.
Assertion (A) : The 3' poly(A) tail of eukaryotic mRNA is not templated by the DNA.
Reason (R) : Poly(A) polymerase adds adenine nucleotides sequentially in a template-independent manner.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

76. During pre-mRNA splicing, the crucial transesterification reaction involves a specific highly conserved nucleotide at the branch site. Which nucleotide is this?

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(A) Guanine
(B) Cytosine
(C) Adenine
(D) Uracil

2025

77. The excised intervening sequence released during nuclear pre-mRNA splicing adopts a specific shape known as a:
(A) Hairpin
(B) Cloverleaf
(C) Circle
(D) Lariat

2025

78. Which sequence motif typically denotes the 5' splice site (donor site) at the intron-exon boundary?
(A) AG
(B) AA
(C) GU
(D) UU

2009

79. Spliceosomes are macromolecular complexes composed of proteins and:
(A) rRNAs
(B) snRNAs
(C) miRNAs
(D) tRNAs

2015

80. Match the post-transcriptional elements in List I with their roles or locations in List II.
List I : (Post-transcriptional element)
P. U1 snRNP
Q. U2 snRNP
R. Poly(A) signal
S. 5' Cap
List II : (Role/Location)
1. AAUAAA sequence
2. Binds 5' splice site
3. Ribosome recognition
4. Binds branch point
(A) P-2, Q-4, R-1, S-3
(B) P-2, Q-1, R-4, S-3
(C) P-4, Q-2, R-3, S-1
(D) P-1, Q-4, R-2, S-3

2025

81. The cleavage and polyadenylation specificity factor (CPSF) recognizes which highly conserved consensus sequence on the pre-mRNA?
(A) AAUAAA
(B) TATAAT
(C) CCAACC
(D) GGGCCC

2025

82. Alternative splicing is a mechanism that allows the cell to:
(A) Degrade mutated mRNA transcripts rapidly
(B) Translate RNA without a ribosome complex
(C) Produce multiple protein isoforms from a single gene
(D) Export DNA from the nucleus to the cytosol

NODIA

2013

83. Group I introns undergo self-splicing. Which cofactor is required for the initiation of this process?
(A) Free guanine nucleotide
(B) High energy ATP
(C) Free adenine base
(D) Reduced NADH

2001

84. Which modification is primarily associated with protecting the mRNA from 5' to 3' exonuclease degradation?
(A) Polyadenylation
(B) RNA editing
(C) Intron excision
(D) 5' Capping

2018

85. The genetic code is described as "degenerate." This term means that:
(A) Codons overlap each other in the sequence
(B) Multiple codons can specify the same amino acid
(C) A single codon specifies multiple amino acids
(D) The genetic code degrades over time periods

2007

86. Which of the following sequences functions as the universal start codon for translation?
(A) UAA
(B) UGA
(C) AUG
(D) UAG

2004

87. In the standard genetic code, how many codons serve as termination (stop) signals?
(A) 1
(B) 2
(C) 3
(D) 4

2011

88. According to the Wobble hypothesis proposed by Francis Crick, flexible base pairing can occur at which position of the codon?
(A) The third position (3' end)
(B) The first position (5' end)
(C) The second position
(D) All positions equally

2004

89. Which amino acid is specified by only a single codon in the standard genetic code?
(A) Leucine
(B) Tryptophan
(C) Arginine
(D) Serine

2009

90. Consider the following statements regarding the features of the genetic code:
I. It is universally identical without exception.
II. It is non-overlapping.
III. It is read continuously without commas.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I

2014

91. The codon UAA is also historically referred to as the:
(A) Ochre codon
(B) Amber codon
(C) Opal codon
(D) Start codon

2010

92. In vertebrate mitochondria, the standard stop codon UGA is reassigned to code for which amino acid?
(A) Selenocysteine
(B) Tyrosine
(C) Tryptophan
(D) Glycine

2024

93. A frameshift mutation is typically caused by which type of genetic alteration?
(A) Substitution of a single nucleotide
(B) Deletion of three nucleotides
(C) Inversion of a sequence
(D) Insertion of a single nucleotide

2014

94. Which modified base at the wobble position of the tRNA anticodon can uniquely pair with U, C, or A in the mRNA codon?
(A) Pseudouridine
(B) Ribothymidine
(C) Inosine
(D) Dihydrouridine

2021

95. The genetic code is termed "unambiguous" because:
(A) Every organism uses exactly the same genetic code
(B) A specific codon designates only one particular amino acid
(C) All mutations change the amino acid sequence of proteins
(D) Amino acids have uniform chemical properties in solution

2002

96. Selenocysteine, the 21st amino acid, is incorporated during translation in response to which specific codon under particular contextual conditions?
(A) AUG
(B) UAA
(C) UAG
(D) UGA

2009

97. The attachment of an amino acid to its corresponding tRNA is catalyzed by which specific class of enzymes?
(A) Aminoacyl-tRNA synthetases
(B) Peptidyl transferases
(C) RNA polymerases
(D) Ribosomal RNA methylases

2016

98. In prokaryotic translation initiation, the small ribosomal subunit recognizes a specific purine-rich sequence on the mRNA called the:
(A) TATA box
(B) Kozak sequence
(C) Shine-Dalgarno sequence
(D) Pribnow box

2018

99. The energy required to charge a tRNA molecule with an amino acid is directly derived from the hydrolysis of:
(A) ATP
(B) GTP
(C) CTP

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2022

33. Heterochromatin is generally characterized by which of the following transcriptional states?
(A) Transcriptionally inactive and tightly condensed
(B) Highly active and loosely packed conformations
(C) Transcriptionally active but tightly condensed
(D) Readily accessible to the RNA polymerase enzyme

2019

34. Which specialized chromatin structure is required for the proper segregation of chromosomes during cell division?
(A) Telomere
(B) Nucleolus
(C) Centromere
(D) Origin of replication

2013

35. DNA gyrase is a specific type of topoisomerase found in bacteria. It belongs to which class?
(A) Type II
(B) Type IA
(C) Type IB
(D) Type III

2005

36. Which structural motif is predominantly utilized by histone proteins to interact with the DNA backbone?
(A) Zinc finger motif
(B) Helix-turn-helix
(C) Leucine zipper
(D) Alpha-helices rich in basic amino acids

2010

37. In E. coli, which enzyme is the primary replicative polymerase responsible for synthesizing the majority of the new DNA strand?
(A) DNA Polymerase I
(B) DNA Polymerase III
(C) DNA Polymerase II
(D) DNA Polymerase IV

2001

38. DNA replication proceeds in a semi-discontinuous manner. The strand synthesized continuously is known as the:
(A) Lagging strand
(B) Coding strand
(C) Leading strand
(D) Template strand

2024

39. What is the primary function of the enzyme primase during DNA replication?
(A) To unwind the parental DNA double helix
(B) To seal single-strand nicks in the DNA
(C) To remove previously synthesized primers
(D) To synthesize a short RNA primer

2001

40. Consider the following statements regarding DNA ligase:
I. It forms a phosphodiester bond.
II. It requires ATP or NAD+ as an energy source.
III. It joins Okazaki fragments on the lagging strand.
IV. It synthesizes RNA primers.
Which of the above statements are correct?
(A) I, II and III
(B) I, II and IV
(C) I, III and IV
(D) II, III and IV

2018

41. Which specific activity of DNA Polymerase I allows it to remove RNA primers from the lagging strand in prokaryotes?
(A) 5' to 3' polymerase activity
(B) 5' to 3' exonuclease activity
(C) 3' to 5' exonuclease activity
(D) Endonuclease activity

2014

42. The unwinding of the parental DNA double helix at the replication fork is driven by which enzyme?
(A) Topoisomerase
(B) DNA Helicase
(C) Single-strand binding protein
(D) Primase

2004

43. Short segments of DNA synthesized on the lagging strand are called:
(A) Okazaki fragments
(B) Klenow fragments
(C) Replisomes
(D) Primer segments

NODIA

2019

44. What prevents separated single-stranded DNA from re-annealing during the replication process?
(A) DNA polymerase enzyme
(B) DNA ligase complexes
(C) Single-strand binding proteins (SSBs)
(D) DNA helicase machinery

I. It marks proteins for degradation.
II. It targets proteins to the proteasome.
III. It requires a single enzyme (E1).
IV. It involves a small 76-amino acid protein.
V. Polyubiquitin chains are linked via lysine residues.

Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) II and III
(C) III
(D) IV and V

2009

111. Protein phosphorylation is a ubiquitous regulatory modification. It predominantly occurs on the hydroxyl groups of which amino acid residues?
(A) Cysteine and methionine
(B) Serine, threonine, and tyrosine
(C) Aspartate and glutamate
(D) Lysine and arginine

2017

112. The attachment of complex carbohydrate chains to the amide nitrogen of an asparagine residue is defined as:
(A) O-linked glycosylation
(B) C-linked glycosylation
(C) Glycation
(D) N-linked glycosylation

2017

113. Molecular chaperones facilitate correct protein folding primarily by:
(A) Preventing inappropriate hydrophobic interactions
(B) Covalently bonding to the misfolded regions
(C) Degrading partially folded proteins
(D) Synthesizing missing peptide sequences

2007

114. The GroEL-GroES complex in E. coli represents a classic example of which chaperone family?
(A) Hsp70
(B) Hsp90
(C) Chaperonins
(D) Small heat shock proteins

2009

115. Match the enzymes in List I with their functions in List II.

List I : (PTM Enzyme)
P. Kinase
Q. Phosphatase
R. Ubiquitin ligase
S. Signal peptidase

List II : (Function)
1. Removes phosphate
2. Adds phosphate
3. Cleaves targeting sequence
4. Attaches degradation tag

(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-2, Q-4, R-1, S-3
(D) P-4, Q-3, R-2, S-1

2019

116. Proteins destined for secretion from a eukaryotic cell typically bear a targeting signal located at which position?
(A) C-terminus
(B) Internal sequence
(C) Poly(A) tail
(D) N-terminus

2004

117. The Signal Recognition Particle (SRP) arrests translation and targets the ribosome to the membrane of which organelle?
(A) Mitochondrion
(B) Endoplasmic reticulum
(C) Golgi apparatus
(D) Lysosome

2002

118. Disulfide bond formation, critical for the tertiary structure of many secreted proteins, occurs primarily in which cellular compartment?
(A) Cytosol
(B) Nucleus
(C) Endoplasmic reticulum lumen
(D) Extracellular matrix

2002

119. Which post-translational modification is predominantly responsible for localizing certain regulatory proteins from the cytosol to the nuclear membrane or plasma membrane?
(A) Acetylation
(B) Methylation
(C) Hydroxylation
(D) Palmitoylation

2005

120. Identify the correct chronological order of events in N-linked protein glycosylation:
I. Trimming of glucose residues
II. Synthesis of dolichol-pyrophosphate oligosaccharide precursor
III. Transfer of oligosaccharide to asparagine
IV. Transport to Golgi for further modification

NODIA

(C) opine catabolism genes
(D) oriV

2017

212. In the commonly used plasmid pBR322, the genes ampicillin resistance (AmpR) and tetracycline resistance (TetR) serve as:
(A) Origins of replication
(B) Promoters
(C) Enhancers
(D) Selectable markers

2018

213. Blue-white screening is a rapid method to identify recombinant bacteria. It relies on the insertional inactivation of which gene?
(A) lacI
(B) lacZ
(C) AmpR
(D) KanR

2008

214. In blue-white screening, successful recombinant colonies carrying an inserted DNA fragment within the MCS appear as:
(A) Blue colonies
(B) Red colonies
(C) White colonies
(D) Clear plaques

2008

215. What limits the insert size capacity of standard plasmid vectors compared to phage or BAC vectors?
(A) Lack of restriction sites
(B) Plasmids cannot replicate large DNA
(C) They lack selectable markers
(D) Transformation efficiency drops sharply with large plasmids

2005

216. Which specific feature of the M13 bacteriophage vector makes it particularly useful for Sanger DNA sequencing?
(A) It allows the recovery of single-stranded cloned DNA.
(B) It accommodates inserts up to 1000 kb.
(C) It expresses genes at very high levels.
(D) It kills the host cell rapidly.

2003

217. A genomic library represents:
(A) Only the genes expressed in a particular tissue
(B) The complete DNA content of an organism
(C) Only the repetitive DNA sequences
(D) Cloned viral genomes

2017

218. A cDNA library is constructed using which specific cellular RNA pool as a template?
(A) Mature mRNA
(B) rRNA
(C) tRNA
(D) snRNA

2024

219. The synthesis of the first cDNA strand from mRNA is catalyzed by reverse transcriptase. Which short molecule is universally used to prime this reaction for eukaryotic mRNAs?
(A) Oligo(dT) primers
(B) Random hexamers
(C) Specific gene primers
(D) RNA primase

2006

220. How does a cDNA library fundamentally differ from a genomic library of a eukaryotic organism?
(A) A cDNA library contains promoters and enhancers.
(B) A cDNA library contains introns.
(C) A cDNA library lacks introns and regulatory regions.
(D) A cDNA library is identical regardless of the tissue of origin.

2008

221. Linkers and adaptors are short synthetic double-stranded DNA oligonucleotides used in cloning. What is their primary purpose?
(A) To label DNA with radioisotopes
(B) To act as promoters for expression
(C) To replicate the plasmid
(D) To provide restriction sites for blunt-ended DNA fragments

2018

222. When screening a library using nucleic acid hybridization, the labeled known sequence used to locate a specific clone is called a:
(A) Vector
(B) Primer
(C) Probe
(D) Marker

2022

223. To construct a highly representative genomic library of a complex eukaryotic genome, which type of vector is most suitable?
(A) Standard plasmid (pUC19)
(B) BAC or YAC

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2007

131. The term "operon" refers to a functioning unit of genomic DNA containing a cluster of genes under the control of a single promoter. This concept was originally proposed by:
(A) Jacob and Monod
(B) Watson and Crick
(C) Hershey and Chase
(D) Beadle and Tatum

2002

132. What is the role of the product encoded by the lacA gene?
(A) It acts as a co-repressor protein
(B) It transports lactose into the cell
(C) It cleaves lactose into its sugars
(D) It acetylates non-metabolizable beta-galactosides for detoxification

2003

133. Epigenetic inheritance involves heritable changes in gene expression that do not arise from alterations in:
(A) Chromatin structure
(B) DNA sequence
(C) Histone modification patterns
(D) DNA methylation states

2017

134. In mammalian genomes, DNA methylation predominantly occurs at the cytosine residue within which specific dinucleotide sequence?
(A) ApT
(B) CpA
(C) CpG
(D) GpC

2001

135. DNA hypermethylation at promoter regions is generally strongly correlated with:
(A) Transcriptional activation
(B) Increased mutation rates
(C) Enhanced splicing
(D) Transcriptional silencing

2009

136. Histone acetylation is catalyzed by Histone Acetyltransferases (HATs) and generally leads to:
(A) Loosening of chromatin structure and transcriptional activation
(B) Tighter packaging of nucleosomes in chromatin
(C) Silencing of adjacent coding genes
(D) Enzymatic DNA degradation

2009

137. Which family of enzymes actively removes acetyl groups from histone tails, promoting chromatin condensation?
(A) Histone methyltransferases (HMTs)
(B) Histone deacetylases (HDACs)
(C) DNA methyltransferases (DNMTs)
(D) Protein kinases

2003

138. The phenomenon where the expression of a gene depends entirely upon the parent of origin (maternal vs. paternal) is known as:
(A) X-chromosome inactivation
(B) Genomic imprinting
(C) Paramutation
(D) Gene amplification

2001

139. ATP-dependent chromatin remodeling complexes (e.g., SWI/SNF) facilitate transcription primarily by:
(A) Sliding or ejecting nucleosomes to expose DNA regulatory elements
(B) Covalently modifying the DNA sequence
(C) Degrading histone proteins in the core
(D) Methylating promoter regions

2015

140. Match the epigenetic marks in List I with their typical transcriptional effects in List II.
List I : (Epigenetic mark)
P. DNA methylation at promoter
Q. Histone acetylation
R. H_3K_9 trimethylation
S. H_3K_4 trimethylation
List II : (Typical Transcriptional Effect)
1. Active promoter mark
2. Heterochromatin formation
3. General transcriptional activation
4. Transcriptional repression
(A) P-4, Q-3, R-2, S-1
(B) P-1, Q-2, R-3, S-4
(C) P-4, Q-1, R-2, S-3
(D) P-2, Q-3, R-4, S-1

2018

141. The regulatory mechanism responsible for dosage compensation in female mammals is called:
(A) Genomic imprinting
(B) Allelic exclusion
(C) RNA interference
(D) X-chromosome inactivation

NODIA

Which of the following is the correct chronological order?
(A) II, III, I, IV
(B) III, II, I, IV
(C) II, I, III, IV
(D) I, II, III, IV

2010

121. In the context of the lac operon, the binding of the repressor protein to the operator sequence exemplifies which type of regulatory control?
(A) Positive inducible
(B) Negative inducible
(C) Positive repressible
(D) Negative repressible

2009

122. The structural gene lacZ of the E. coli lac operon encodes which functional enzyme?
(A) Lactose permease
(B) Beta-galactosidase
(C) Thiogalactoside transacetylase
(D) Adenylate cyclase

2012

123. What acts as the natural inducer of the lac operon by binding directly to the repressor protein?
(A) Allolactose
(B) Glucose
(C) cAMP
(D) Isopropyl β-D-1-thiogalactopyranoside (IPTG)

2025

124. Catabolite repression in the lac operon is mediated by cAMP and the CAP protein. When glucose levels in the cell are high, what is the status of cAMP?
(A) cAMP levels are high.
(B) cAMP is converted to ATP.
(C) cAMP levels are low.
(D) cAMP continuously binds CAP.

2022

125. The trp operon in E. coli regulates the biosynthesis of tryptophan and is a classic model for:
(A) Negative inducible control
(B) Positive repressible control
(C) Positive inducible control
(D) Negative repressible control

2008

126. Attenuation is a secondary regulatory mechanism in the trp operon that controls gene expression by:
(A) Inhibiting initiation of transcription
(B) Blocking the ribosome from starting translation
(C) Promoting premature termination of transcription
(D) Degrading the trp repressor

2025

127. In the attenuation model of the trp operon, which specific mRNA stem-loop structure functions as the intrinsic transcription terminator?
(A) 1-2 loop
(B) 3-4 loop
(C) 2-3 loop
(D) 1-4 loop

2021

128. If an E. coli cell carries a mutation in the lacI gene (lacI-) preventing repressor synthesis, what is the expected phenotype regarding beta-galactosidase expression?
(A) Permanent repression regardless of lactose presence
(B) Expression only when lactose is absent
(C) Expression only when glucose is high
(D) Constitutive expression regardless of lactose presence

2011

129. Which trans-acting factor is required for the positive regulation of multiple sugar-metabolizing operons in response to glucose deprivation?
(A) CAP (Catabolite Activator Protein)
(B) AraC
(C) TrpR
(D) LexA

2003

130. Read the following statements and select the correct option.
Assertion (A) : In the presence of both glucose and lactose, the lac operon is expressed at maximal levels.
Reason (R) : Lactose binds the repressor, removing it from the operator, allowing unrestricted transcription.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

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2012

154. Chloroplast ribosomes are structurally most similar to those found in:
(A) The eukaryotic cytosol
(B) Prokaryotic cells (70S)
(C) Animal mitochondria (55S)
(D) Fungi

2008

155. Which critical enzyme complex involved in photosynthesis has components encoded by both the nuclear and chloroplast genomes?
(A) Ribulose-1,5-bisphosphate carboxylase/ oxygenase (RuBisCO)
(B) The multi-subunit nitrogenase enzyme complex
(C) The mitochondrial ATP synthase complex
(D) Membrane-bound cytochrome c oxidase enzymes

2013

156. Invarient transmission of CMS traits over multiple generations of backcrossing with a recurrent male parent indicates the trait is:
(A) Sex-linked
(B) Epigenetic
(C) Extranuclear
(D) Autosomal recessive

2016

157. Bacteriophages that can integrate their genome into the host chromosome and establish a dormant state are termed:
(A) Virulent phages
(B) Lytic phages
(C) Myoviruses
(D) Temperate phages

2024

158. The integrated viral genome in a lysogenic bacterium is specifically referred to as a:
(A) Plasmid
(B) Viroid
(C) Prophage
(D) Transposon

2014

159. In the life cycle of bacteriophage lambda, which specific repressor protein is critical for maintaining the lysogenic state?
(A) Cro protein
(B) CI repressor (Lambda repressor)
(C) CII protein
(D) N protein

2013

160. Consider the following events characterizing viral life cycles:
I. Integration into host genome
II. Host cell lysis
III. Rapid production of virions
IV. Dormancy
Which of the above events are characteristic of the lytic cycle?
(A) I and II
(B) II and III
(C) III and IV
(D) I and IV

2014

161. Retroviruses possess an RNA genome but rely on an intermediate DNA stage. Which viral enzyme synthesizes the DNA copy from the viral RNA?
(A) Reverse transcriptase
(B) Integrase
(C) RNA replicase
(D) Protease

2024

162. The process by which an integrated retroviral DNA (provirus) generates new viral RNA genomes is mediated by which host cell machinery?
(A) Host DNA polymerase
(B) Host ribosomes alone
(C) Host RNA polymerase II
(D) Viral RNA replicase

NODIA

2004

163. Plant viruses most frequently utilize which vector type for transmission between plant hosts?
(A) Insect vectors (e.g., aphids)
(B) Water droplets
(C) Wind
(D) Soil bacteria

2023

164. Most known plant viruses, such as the Tobacco Mosaic Virus (TMV), possess a genome composed of:
(A) Double-stranded DNA
(B) Single-stranded DNA
(C) Negative-sense single-stranded RNA
(D) Positive-sense single-stranded RNA

2015

165. How do plant viruses typically move from one infected cell to an adjacent uninfected cell within the host plant?
(A) Through active lysis and release
(B) Via plasmodesmata

(C) Through specific cell-wall receptors
(D) By forming syncytia

2018

166. In bacteriophage lambda, the "decision" between the lytic and lysogenic pathways is fundamentally a competition between which two regulatory proteins?
(A) Cro protein
(B) N and Q
(C) CI and Cro
(D) Sigma and Rho

2004

167. Induction of a lysogenic prophage, causing it to enter the lytic cycle, is typically triggered by:
(A) Abundant host nutrient levels
(B) Increased ambient temperature only
(C) High cellular ATP levels
(D) Cellular DNA damage and the SOS response

2010

168. The enzyme integrase, encoded by retroviruses, performs which specific function?
(A) Insertion of viral DNA into the host chromosome
(B) Uncoating of the viral capsid
(C) Synthesis of viral cDNA
(D) Cleavage of viral polyproteins

2003

169. Ultraviolet (UV) radiation primarily damages cellular DNA by inducing the formation of:
(A) Double-strand breaks
(B) Pyrimidine dimers
(C) Base methylations
(D) Apurinic sites

2011

170. Consider the following statements regarding chemical mutagens:
I. Nitrous acid causes deamination.
II. Ethidium bromide is an intercalating agent.
III. 5-Bromouracil acts as a base analog.
IV. Alkylating agents cannot induce transversions.
V. Base analogs exclusively cause frameshifts.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and V
(C) I, III and IV
(D) I, IV and V

2024

171. Base Excision Repair (BER) is initiated by which specific class of enzymes that recognize and remove modified bases?
(A) DNA glycosylases
(B) Endonucleases
(C) DNA polymerases
(D) Ligases

2004

172. Nucleotide Excision Repair (NER) is uniquely adapted to repair which type of DNA lesion?
(A) Single missing bases
(B) Small alkylation adducts
(C) Bulky, helix-distorting lesions
(D) Double-strand breaks

2013

173. In E. coli, the mismatch repair (MMR) system distinguishes the newly synthesized DNA strand from the template strand by recognizing:
(A) Transient single-strand breaks in the DNA backbone
(B) Residual RNA primers present on the lagging strand
(C) Specific sequence recognition tags in the genome
(D) The absence of methylation on the newly synthesized strand

2014

174. Which of the following mutations results in the premature introduction of a stop codon into the coding sequence?
(A) Missense mutation
(B) Silent mutation
(C) Nonsense mutation
(D) Splice-site mutation

2001

175. The spontaneous loss of an amino group from cytosine converts it into which nitrogenous base?
(A) Thymine
(B) Uracil
(C) Adenine
(D) Guanine

2015

176. Deamination of 5-methylcytosine produces which specific base, often leading to a C-to-T transition mutation if unrepaired?
(A) Uracil
(B) Xanthine
(C) Hypoxanthine
(D) Thymine

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2015

177. Which repair mechanism directly reverses UV-induced pyrimidine dimers using energy derived from visible light?
(A) Photoreactivation
(B) Recombination repair
(C) Nucleotide excision repair
(D) Base excision repair

2012

178. A transition mutation involves which type of base substitution?
(A) Purine to Pyrimidine
(B) Pyrimidine to Purine
(C) Purine to Purine or Pyrimidine to Pyrimidine
(D) Insertion of an extra base

2015

179. If severe DNA damage stalls the replication fork in bacteria, which error-prone repair mechanism is activated as a last resort?
(A) SOS response
(B) Mismatch repair
(C) Photoreactivation
(D) Homologous recombination

2017

180. Identify the correct chronological sequence of events in the Base Excision Repair (BER) pathway:
I. DNA ligase seals the nick.
II. AP endonuclease cuts the backbone.
III. DNA glycosylase removes the damaged base.
IV. DNA polymerase fills the gap.
Which of the following is the correct chronological sequence of events?
(A) III, II, IV, I
(B) II, III, IV, I
(C) III, IV, II, I
(D) II, IV, III, I

2002

181. Normal cellular genes that promote cell growth and division, but can become oncogenic upon mutation, are known as:
(A) Tumor suppressor genes
(B) Proto-oncogenes
(C) Apoptotic genes
(D) DNA repair genes

2008

182. A gain-of-function mutation in a proto-oncogene typically requires how many mutant alleles to contribute to carcinogenesis?
(A) Two
(B) Three
(C) One
(D) Zero

NODIA

2021

183. Which of the following is a classic example of a tumor suppressor gene?
(A) Ras
(B) Myc
(C) Src
(D) p53

2024

184. The "two-hit hypothesis" proposed by Alfred Knudson applies to the mutation kinetics of which class of cancer-associated genes?
(A) Tumor suppressor genes
(B) Oncogenes
(C) Proto-oncogenes
(D) Telomerase genes

2019

185. The Retinoblastoma (Rb) protein acts as a tumor suppressor by binding and inhibiting which key cell cycle transcription factor?
(A) p21
(B) E_2F
(C) Cyclin D
(D) CDK4

2025

186. The p53 protein regulates the cell cycle predominantly at which specific checkpoint in response to DNA damage?
(A) S/G2 transition
(B) G1/S transition
(C) G2/M transition
(D) Spindle assembly checkpoint

2018

187. Many oncogenes encode proteins that are persistently active forms of normal cellular components. Which class of protein is frequently encoded by the Ras oncogene?
(A) Small GTPase
(B) Transcription factor
(C) Transmembrane receptor
(D) Kinase

2008

188. Dysregulation of apoptosis is a hallmark of cancer. Which of the following proteins generally exerts an anti-apoptotic effect?
(A) Bax
(B) Bak
(C) Bcl-2
(D) Caspase-9

2012

189. A chromosomal translocation t(9;22) results in the Philadelphia chromosome, causing Chronic Myelogenous Leukemia. Which fusion oncogene is generated by this event?
(A) MYC-IGH
(B) PML-RARA
(C) EWS-FLI1
(D) BCR-ABL

2014

190. Read the following statements and select the correct option.
Assertion (A) : In cancer cells, telomerase activity is often significantly upregulated.
Reason (R) : Upregulation of telomerase prevents replicative senescence, conferring cellular immortality.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2009

191. Loss of heterozygosity (LOH) is a genetic event commonly associated with the inactivation of:
(A) Dominant oncogenes
(B) Tumor suppressor genes
(C) Recessive oncogenes
(D) Enhancer elements

2021

192. Which cellular kinase complexes are the primary targets of regulation during cell cycle progression?
(A) Tyrosine kinases
(B) MAP kinases
(C) PI3 kinases
(D) Cyclin-dependent kinases (CDKs)

2012

193. Restriction endonucleases evolved naturally in bacteria primarily to serve which function?
(A) Provide defense against viral (bacteriophage) infection
(B) Facilitate genetic recombination
(C) Repair bacterial DNA
(D) Synthesize RNA primers

2013

194. Type II restriction endonucleases are preferred in recombinant DNA technology because they:
(A) Cleave DNA randomly.
(B) Require ATP for cleavage.
(C) Cleave DNA at precise locations within or adjacent to their recognition sites.
(D) Only methylate the DNA without cutting.

2006

195. The characteristic feature of recognition sequences for Type II restriction enzymes is that they are generally:
(A) Palindromic
(B) AT-rich regions
(C) Direct repeats
(D) Variable in length

2015

196. When a restriction enzyme like EcoRI cuts double-stranded DNA, it leaves single-stranded overhangs known as:
(A) Blunt ends
(B) Flush ends
(C) 5' caps
(D) Sticky or cohesive ends

2015

197. Which enzyme is utilized in vitro to covalently join an inserted DNA fragment with a vector DNA molecule?
(A) DNA Polymerase I
(B) DNA Ligase
(C) Reverse Transcriptase
(D) Alkaline Phosphatase

2019

198. The nomenclature of restriction enzymes (e.g., HindIII) is derived from the:
(A) Target DNA sequence
(B) Type of ends produced
(C) Genus, species, and strain of the source bacterium
(D) Name of the discovering scientist

2008

199. What is the standard function of the modification methylase in a bacterial restriction-modification system?
(A) To degrade foreign DNA
(B) To initiate DNA replication
(C) To promote viral integration
(D) To protect the host DNA from cleavage by its own restriction enzyme

2013

200. Match the enzymes in List I with their recombinant DNA functions in List II.
List I : (Enzyme)
P. Alkaline phosphatase
Q. Reverse transcriptase
R. T4 DNA ligase

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S. Restriction endonuclease

List II : (Recombinant Function)

1. Generates cDNA
2. Covalently joins DNA
3. Prevents vector self-ligation
4. Cleaves DNA specifically

(A) P-3, Q-1, R-2, S-4
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-2, R-1, S-4
(D) P-2, Q-3, R-4, S-1

2017

201. Type I restriction endonucleases are rarely used in cloning because they:
(A) Have no methylation activity.
(B) Cleave DNA at random sites far from the recognition sequence.
(C) Require no ATP.
(D) Only cut single-stranded DNA.

2015

202. The enzyme Terminal Deoxynucleotidyl Transferase (TdT) is utilized in molecular cloning to:
(A) Remove phosphate groups
(B) Add homopolymeric tails to the 3' ends of DNA fragments
(C) Cut DNA at non-palindromic sequences
(D) Unwind double-stranded DNA

2010

203. Isochizomers are different restriction endonucleases that:
(A) Recognize the exact same DNA sequence
(B) Cut RNA instead of DNA
(C) Produce identical sticky ends from different recognition sites
(D) Only cut methylated DNA

2019

204. During a cloning experiment, alkaline phosphatase is applied to the vector DNA primarily to:
(A) Facilitate the binding of RNA polymerase
(B) Add a 3'-hydroxyl group for ligation
(C) Remove 5'-phosphate groups, thereby preventing self-circularization
(D) Increase the efficiency of restriction enzyme digestion

2023

205. Plasmids used as cloning vectors must naturally contain which of the following essential sequence elements to ensure their propagation in host cells?
(A) Telomeres
(B) Centromere
(C) Promoter for every inserted gene
(D) Origin of replication (ori)

2021

206. A unique restriction site where foreign DNA can be inserted without disrupting essential vector functions is commonly located within a region known as the:
(A) Selectable marker
(B) Replication origin
(C) Multiple cloning site (MCS)
(D) Promoter

2025

207. Which cloning vector is uniquely designed to accommodate extremely large inserts (up to 300 kb) by utilizing the F-factor replicon?
(A) Cosmid
(B) Bacterial Artificial Chromosome (BAC)
(C) Phagemid
(D) Yeast Artificial Chromosome (YAC)

2010

208. Yeast Artificial Chromosomes (YACs) require specific structural elements to function as chromosomes in yeast. Which of the following is NOT required for a YAC?
(A) Centromere (CEN)
(B) Telomeres (TEL)
(C) Autonomous replicating sequence (ARS)
(D) F-factor origin (oriS)

2014

209. Cosmids are hybrid cloning vectors constructed from plasmids and elements of which biological entity?
(A) Bacteriophage lambda (cos sites)
(B) Eukaryotic viruses
(C) Agrobacterium tumefaciens
(D) Retroviruses

2002

210. Which vector type is most extensively used for generating transgenic crops due to its natural ability to transfer DNA into plant genomes?
(A) pBR322
(B) Baculovirus vector
(C) Ti plasmid of Agrobacterium tumefaciens
(D) M13 bacteriophage

2025

211. The part of the Ti plasmid that is transferred and stably integrated into the plant nuclear genome is called:
(A) T-DNA
(B) vir region

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2002

142. Which non-coding RNA molecule is essentially required to initiate silencing of the inactive X chromosome in mammals?
(A) HOTAIR
(B) SRA
(C) XIST
(D) MALAT1

2002

143. Which of the following histone modifications is typically recognized as a hallmark of transcriptionally active promoter regions?
(A) H3K9me3
(B) H3K4me3
(C) H3K27me3
(D) H4K20me3

2006

144. Maintenance DNA methyltransferases (such as DNMT1) ensure epigenetic inheritance by acting selectively on:
(A) Fully methylated DNA
(B) Unmethylated DNA
(C) RNA-DNA hybrids
(D) Hemimethylated DNA during replication

2011

145. The endosymbiotic theory suggests that chloroplasts and mitochondria evolved from free-living:
(A) Bacteria
(B) Eukaryotic algae
(C) Archaea
(D) Fungi

2018

146. Which structural feature characterizes the typical mitochondrial genome (mtDNA) in animals?
(A) Linear, single-stranded DNA
(B) Linear, double-stranded RNA
(C) Circular, double-stranded DNA
(D) Circular, single-stranded DNA

2013

147. In most angiosperms, the transmission of the chloroplast genome occurs primarily via:
(A) Maternal inheritance
(B) Biparental inheritance
(C) Paternal inheritance
(D) Horizontal gene transfer

2015

148. Cytoplasmic Male Sterility (CMS) in crop plants is agronomically important for the production of hybrid seeds. The genetic determinants for CMS are predominantly located in the:
(A) Nuclear genome
(B) Chloroplast genome
(C) Ribosomal DNA
(D) Mitochondrial genome

NODIA

2022

149. In CMS-based hybrid seed production, fertility can be restored in the F1 hybrid by incorporating which specific nuclear genes?
(A) Male sterility (Ms) genes
(B) Restorer of fertility (Rf) genes
(C) Pathogenesis-related (PR) genes
(D) Homeotic genes

2011

150. Consider the following statements regarding the chloroplast genome (cpDNA):
I. It contains inverted repeats.
II. It codes for the large subunit of RuBisCO.
III. It relies entirely on nuclear ribosomes for translation.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) II

2015

151. Which term describes the condition in a single cell where two or more distinct variants of organellar genomes (e.g., mutant and wild-type mtDNA) coexist?
(A) Homoplasmy
(B) Aneuploidy
(C) Polyploidy
(D) Heteroplasmy

2024

152. The maternal inheritance of mitochondrial traits in mammals is primarily due to:
(A) Degradation of paternal mitochondria after fertilization
(B) The larger size of the egg cell
(C) Lack of mitochondria in sperm cells
(D) Recombination between maternal and paternal mtDNA

2013

153. Plant mitochondrial genomes differ from animal mitochondrial genomes in that plant mtDNAs are generally:
(A) Much smaller and highly conserved
(B) Much larger and undergo frequent recombination
(C) Linear and single-stranded
(D) Devoid of functional genes

(C) M13 Phage
(D) Expression vector

2014

224. Which enzyme is used in cDNA synthesis to degrade the RNA strand of the RNA-DNA hybrid, allowing synthesis of the second DNA strand?
(A) DNase I
(B) S1 Nuclease
(C) RNA Polymerase
(D) RNase H

2010

225. Expression libraries differ from standard genomic libraries primarily because the vectors in an expression library contain:
(A) Functional promoter and ribosome binding sites for the host
(B) Telomeres
(C) No selectable markers
(D) Intron sequences

2014

226. When using immunological screening (e.g., antibodies) to find a specific clone in a library, the library must specifically be a(n):
(A) Genomic library
(B) RNA library
(C) Expression library
(D) BAC library

2003

227. The size of the DNA fragments generated for genomic library construction is typically optimized by using:
(A) Partial digestion with restriction enzymes
(B) Complete digestion with frequent cutters
(C) High-temperature denaturation
(D) Treatment with strong acids

2002

228. Adaptors are superior to linkers for adding restriction sites to blunt ends because adaptors:
(A) Are synthesized in vivo
(B) Contain origins of replication
(C) Act as primers for sequencing
(D) Have pre-formed cohesive ends, preventing their self-ligation

2011

229. Chromosome walking is a technique used in gene mapping to:
(A) Identify protein-protein interactions
(B) Isolate overlapping genomic clones to traverse large chromosomal regions
(C) Move chromosomes during mitosis
(D) Delete specific genes from a chromosome

2018

230. A major limitation of traditional chromosome walking in eukaryotic genomes is the presence of:
(A) High AT content
(B) Telomeres
(C) Dispersed highly repetitive DNA sequences
(D) Circular DNA

2010

231. Chromosome jumping is advantageous over chromosome walking because it allows researchers to:
(A) Directly synthesize the entire chromosome
(B) Avoid using restriction enzymes entirely
(C) Sequence the genome without cloning
(D) Bypass unclonable or repetitive regions by connecting distant loci

2025

232. Transposon tagging is an elegant strategy for gene isolation. It fundamentally relies on identifying a gene by:
(A) Inducing a mutant phenotype through the insertion of a known mobile genetic element
(B) Mapping its promoter sequence
(C) Synthesizing the gene chemically
(D) Measuring protein activity

2015

233. The classical transposon system widely used for gene tagging in maize genetics was first discovered by Barbara McClintock. This system is known as:
(A) Ty elements
(B) Ac/Ds elements
(C) P elements
(D) Alu elements

2002

234. In map-based cloning (positional cloning), isolating a target gene depends fundamentally on knowing its:
(A) Amino acid sequence
(B) Precise function
(C) Genetic map position relative to closely linked markers
(D) Expression profile

2021

235. Which molecular marker system relies on the amplification of random DNA segments using short arbitrary primers?
(A) RAPD

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different classes of genes. RNA polymerase one is responsible for transcribing most ribosomal RNA, while RNA polymerase three transcribes transfer RNA. RNA polymerase two is the specific enzyme that transcribes all protein-coding genes, producing the precursor messenger RNA that is later processed into mature mRNA.

20. (A) P-3, Q-1, R-2, S-4
Different RNA types perform specialized roles in gene expression. Messenger RNA provides the genetic template for protein synthesis. Transfer RNA decodes this information by bringing specific amino acids to the ribosome. Ribosomal RNA serves as the catalyst for peptide bond formation. Finally, microRNAs regulate the process by silencing specific genes through the degradation or repression of their transcripts.

21. (B) 3'-CCA terminus
Transfer RNA molecules serve as adapters that link specific codons to their corresponding amino acids. Every tRNA molecule ends with a highly conserved sequence of three nucleotides at its three-prime end. The amino acid is covalently attached to the hydroxyl group of the terminal adenosine in this sequence. This attachment is catalyzed by specific enzymes and provides energy.

22. (B) 70S
Prokaryotic ribosomes are complex macromolecular machines composed of two unequal subunits. The small subunit has a sedimentation coefficient of thirty-S, while the large subunit has a coefficient of fifty-S. When these two subunits come together on a messenger RNA molecule to initiate translation, they form a functional intact ribosome with a total sedimentation coefficient of seventy-S units in bacteria.

23. (D) Bacteria
In prokaryotic organisms like bacteria, genes with related functions are often clustered together into a single transcriptional unit called an operon. This arrangement results in the production of polycistronic messenger RNA, which contains the coding sequences for multiple different proteins. This allows the cell to coordinate the synthesis of all components of a metabolic pathway or complex efficiently.

24. (A) Pseudouridine
Transfer RNA contains several chemically modified bases that are not found in standard RNA transcripts. The T-psi-C loop, located on one arm of the cloverleaf structure, is named for a conserved sequence containing thymidine, pseudouridine, and cytidine. Pseudouridine is a C-glycosidic isomer of uridine. This specific modification is thought to stabilize the tertiary structure and facilitate ribosome interaction.

25. (B) Nucleosome
The primary level of DNA organization in the nucleus involves the wrapping of the double helix around a core of alkaline proteins. This fundamental repeating unit of chromatin is composed of approximately one hundred and forty-six base pairs of DNA coiled around a histone octamer. This structure resembles beads on a string and is essential for compacting the genome.

26. (B) H1
The nucleosome core particle consists of an octameric complex of histone proteins. This octamer is composed of two copies each of histones H2A, H2B, H3, and H4. While histone H1 is also involved in chromatin organization, it is not part of the core octamer itself. Instead, it binds to the linker DNA outside the core to stabilize higher-order packaging.

NODIA

27. (C) 146 base pairs
Chromatin packaging starts with the formation of nucleosomes, where DNA is wound around a protein core. Precise experimental measurements have determined that exactly one hundred and forty-six base pairs of DNA are required to wrap around a single histone octamer core approximately one point six seven times. This conserved length of DNA is protected from nuclease digestion by protein association.

28. (C) Type I Topoisomerase
During processes like replication and transcription, the DNA double helix can become overwound or underwound, creating torsional stress. Type one topoisomerases are specialized enzymes that resolve this supercoiling by introducing a transient break in only one of the two DNA strands. After allowing the DNA to rotate and relax, the enzyme reseals the nick without requiring high-energy bonds.

(D) Polysaccharides

2010

247. The chemical reagent fundamentally critical for coupling to the N-terminal amino acid during Edman degradation is:
(A) Ninhydrin
(B) Beta-mercaptoethanol
(C) Cyanogen bromide
(D) Phenyl isothiocyanate (PITC)

2015

248. Mass spectrometry (e.g., MALDI-TOF) has largely replaced Edman degradation for protein identification because it allows for:
(A) Rapid analysis of very low abundance complex peptide mixtures
(B) Reading the DNA directly
(C) Chemical synthesis of proteins
(D) Sequencing of entire whole cells

2024

249. Which third-generation sequencing platform generates ultra-long reads by measuring changes in electrical conductivity as a single-stranded DNA molecule translocates through a synthetic or biological channel?
(A) 454 Pyrosequencing
(B) Oxford Nanopore
(C) SOLiD
(D) Sanger Capillary Sequencing

2003

250. Read the following statements and select the correct option.
Assertion (A) : Sanger sequencing is still frequently used for verifying cloned sequences or targeted mutations.
Reason (R) : Despite lower throughput compared to NGS, Sanger sequencing provides highly accurate sequence data for individual, short DNA templates.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2017

251. Which specialized technique maps the physical interaction sites between a DNA-binding protein and its target sequence by detecting protected regions from nuclease digestion?
(A) DNA Footprinting
(B) Yeast Two-Hybrid
(C) Southern Blotting
(D) PCR

2023

252. The generation of a cDNA fragment directly from an RNA template utilizing specific primers, followed by standard DNA amplification, is known as:
(A) Real-Time PCR
(B) Multiplex PCR
(C) RT-PCR (Reverse Transcription PCR)
(D) Inverse PCR

2008

253. The "C-value" of a species refers strictly to:
(A) The number of chromosomes in a diploid cell
(B) The percentage of cytosine in the genome
(C) The number of coding genes
(D) The total amount of DNA in a haploid genome

2013

254. The "C-value paradox" highlights the observation that:
(A) Genome size perfectly correlates with organismal complexity.
(B) Plants always have smaller genomes than animals.
(C) Genome size does not tightly correlate with evolutionary complexity.
(D) Gene density is uniform across all kingdoms.

2021

255. In the eukaryotic genome, Long Interspersed Nuclear Elements (LINEs) and Short Interspersed Nuclear Elements (SINEs) represent major classes of:
(A) Simple Sequence Repeats
(B) Retrotransposons
(C) Telomeric repeats
(D) Ribosomal RNA genes

2010

256. Which of the following is the most prominent human SINE family, comprising over 10% of the entire human genome?
(A) L1 element
(B) Copia element
(C) Ty element
(D) Alu element

2011

257. Genetic mapping relies on estimating distances between loci based on:
(A) Recombination frequencies during meiosis
(B) Actual physical base pair distances

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(C) Nucleotide sequence homology
(D) Protein expression levels

2014

258. Physical mapping specifies distances between chromosomal landmarks in units of:
(A) CentiMorgans (cM)
(B) Map units (m.u.)
(C) Base pairs (bp, kb, Mb)
(D) Recombination fractions

2014

259. A fundamental difference between a genetic map and a physical map is that:
(A) Genetic distances vary depending on recombination hotspots, whereas physical distances are absolute.
(B) Physical maps are always smaller.
(C) Genetic maps only map RNA.
(D) Physical maps do not apply to eukaryotes.

2025

260. Match the genome elements in List I with their descriptions in List II.
List I : (Genome Element)
P. Microsatellite
Q. LINE
R. Centromere
S. Pseudogene
List II : (Description)
1. Non-functional gene copy
2. Autonomous retrotransposon
3. Short tandem repeat marker
4. Spindle attachment region
(A) P-3, Q-2, R-4, S-1
(B) P-1, Q-4, R-2, S-3
(C) P-3, Q-4, R-2, S-1
(D) P-2, Q-3, R-1, S-4

2018

261. Highly repetitive, tandemly arrayed DNA sequences found primarily concentrated near centromeres and telomeres are called:
(A) SINEs
(B) Satellite DNA
(C) Exons
(D) Introns

2003

262. Non-autonomous transposable elements, such as Ds in maize, require the presence of an autonomous element (like Ac) specifically to provide:
(A) A promoter
(B) Origin of replication
(C) Functional transposase enzyme
(D) Primer for transcription

2006

263. Synteny, an important concept in comparative genomics, refers to the:
(A) Total DNA content of a cell
(B) Rate of mutation in a genome
(C) Ability of genomes to replicate
(D) Conservation of gene order and blocks of genes on chromosomes of different species

2007

264. The primary reason for the vast difference in genome sizes among closely related plant species (e.g., within grasses) is largely attributable to variations in:
(A) Proliferation of retrotransposons and polyploidy events
(B) The number of essential metabolic genes
(C) The size of individual exons
(D) Telomere length

2013

265. Transcriptomics is defined as the comprehensive study of:
(A) All the proteins expressed in a cell
(B) All RNA transcripts produced by the genome under specific conditions
(C) The complete set of metabolic intermediates
(D) All epigenetic modifications

2015

266. Which high-throughput technique allows researchers to simultaneously measure the relative expression levels of thousands of genes?
(A) Edman Degradation
(B) DNA Microarrays
(C) Sanger Sequencing
(D) Southern Blotting

NODIA

2013

267. In a two-color DNA microarray experiment, mRNA from control cells and treated cells are reverse-transcribed into cDNA and labeled with two distinct fluorophores. What is typically indicated by a yellow spot on the array image?
(A) The gene is equally expressed in both control and treatment conditions.
(B) The gene is not expressed in either condition.
(C) The gene is highly expressed only in the control.
(D) The gene is highly expressed only in the treatment.

2010

268. RNA-Seq has largely surpassed microarrays for transcriptomic analysis primarily because RNA-Seq:
(A) Requires knowledge of the genome sequence beforehand
(B) Is less sensitive to highly expressed genes
(C) Detects novel transcripts and splice variants without relying on pre-designed probes
(D) Cannot quantify transcript abundance

2025

269. The field of Proteomics faces unique analytical challenges not seen in Genomics. Which of the following is a major factor contributing to proteome complexity?
(A) The strict one-gene to one-protein rule
(B) The high stability of all proteins
(C) Uniform protein concentrations across all tissues
(D) Alternative splicing and post-translational modifications (PTMs)

2002

270. In shotgun proteomics, complex protein mixtures are first digested into smaller peptides using a specific protease before mass spectrometry analysis. The most commonly used protease is:
(A) Pepsin
(B) Chymotrypsin
(C) Trypsin
(D) Papain

2022

271. Two-dimensional gel electrophoresis (2D-PAGE) separates proteins based on two independent biochemical properties. What are they?
(A) Mass and hydrophobicity
(B) Isoelectric point (pI) and molecular weight
(C) Charge and affinity
(D) Shape and catalytic activity

2021

272. Automated solid-phase oligonucleotide synthesis conventionally proceeds in which chemical direction?
(A) 5' to 3'
(B) N-terminus to C-terminus
(C) C-terminus to N-terminus
(D) 3' to 5'

2021

273. During the automated synthesis of DNA oligonucleotides, the reactive groups of the nucleoside phosphoramidite monomers must be temporarily masked. The 5'-hydroxyl group is typically protected by:
(A) Dimethoxytrityl (DMT) group
(B) Cyanoethyl group
(C) Fmoc group
(D) Boc group

2004

274. Which analytical method is broadly used to identify the precise protein components of a molecular complex isolated via immunoprecipitation?
(A) X-ray crystallography
(B) Nuclear Magnetic Resonance
(C) LC-MS/MS (Liquid Chromatography-Tandem Mass Spectrometry)
(D) Western blotting with random antibodies

2025

275. Forward genetics refers to the classical approach of determining the genetic basis responsible for a phenotype. Conversely, "Reverse genetics" starts with:
(A) A known DNA sequence to determine its resultant phenotype by targeted disruption
(B) A known mutant phenotype to find the gene
(C) An unknown RNA transcript
(D) A synthesized protein to build a cell

2007

276. Which system, derived from bacterial adaptive immunity, has become the premier tool for targeted genome editing and functional genomics in eukaryotes?
(A) RNA interference (RNAi)
(B) Zinc Finger Nucleases (ZFNs)
(C) TALENs
(D) CRISPR-Cas9

2012

277. The Basic Local Alignment Search Tool (BLAST) is fundamentally utilized to:
(A) Design PCR primers
(B) Identify homologous sequences by comparing a query sequence against a database
(C) Predict secondary protein structure
(D) Construct phylogenetic trees

2013

278. In sequence alignment algorithms, a "gap penalty" is assigned to:
(A) Matches between identical bases
(B) Mismatches between different bases
(C) The insertion or deletion of sequences in the alignment
(D) The statistical significance score

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ANSWERS

1. (A) Uracil
In the structure of nucleic acids, uracil is the specific pyrimidine base present in RNA that replaces thymine found in DNA. Structurally, uracil differs from thymine because it lacks a methyl group at the fifth carbon position of its heterocyclic ring. This subtle chemical difference allows for the unique biochemical identification and processing of ribonucleic acid molecules.

2. (C) $\frac{A+G}{C+T}$
According to Chargaff's rules for double-stranded DNA, the total amount of purines must equal the total amount of pyrimidines. Specifically, the molar concentration of adenine equals thymine, and guanine equals cytosine. Consequently, the sum of adenine and guanine divided by the sum of cytosine and thymine always yields a ratio of exactly one in any genomic sample.

3. (A) Phosphodiester bond
Nucleic acid polymers are formed through the establishment of strong covalent linkages between adjacent nucleotide units. This specific chemical connection occurs when the phosphate group attached to the 5-prime carbon of one sugar molecule reacts with the 3-prime hydroxyl group of the preceding sugar. This repeating structural motif creates a stable and directional sugar-phosphate backbone for DNA and RNA.

4. (D) Z-form
While most DNA adopts a right-handed helical structure, certain sequences can transition into an alternative left-handed conformation. This specific variant is characterized by a distinctive zig-zag appearance of the sugar-phosphate backbone due to the alternating orientations of the glycosidic bonds. It is typically favored by sequences containing alternating purine and pyrimidine residues under conditions of high salt.

5. (B) N-1
Nucleosides are formed through the creation of a covalent N-glycosidic bond between a nitrogenous base and a pentose sugar. In the case of pyrimidine bases like cytosine or uracil, the bond connects the nitrogen atom at position one to the one-prime carbon of the ribose or deoxyribose. This geometry is essential for the proper orientation of the base.

6. (C) Negative
The backbone of a DNA molecule is composed of repeating sugar and phosphate units. At physiological pH, the hydroxyl groups of the phosphoric acid residues are ionized, resulting in the loss of protons. This biochemical state leaves each phosphate group with a net negative charge, making the overall nucleic acid molecule a highly polyanionic structure within the cellular environment.

NODIA

7. (D) Dehydration
The conformation of DNA is highly sensitive to its immediate chemical environment and hydration state. Under conditions of reduced water availability or dehydration, the standard right-handed B-DNA helix undergoes a structural transition into the more compact A-DNA form. This change involves a widening of the helix and a shift in the tilt of the base pairs relative to the axis.

8. (B) 10.5
Under standard physiological conditions, the double-stranded DNA molecule typically exists in the B-form. This right-handed helical structure is characterized by specific geometric parameters, including a helical pitch of approximately thirty-four angstroms. Within each complete three-hundred-and-sixty-degree turn of this helix, there are roughly ten-point-five base pairs, which ensures the stability and accessibility of the genetic code for transcription.

9. (B) GC-rich DNA has a lower melting temperature than AT-rich DNA.
DNA denaturation involves the separation of the two strands due to the breaking of hydrogen bonds between complementary bases. Since guanine and cytosine are joined by three hydrogen bonds, while adenine and thymine have only two, GC-rich regions are more thermally stable. Therefore, DNA with a higher GC content requires more energy and has a higher melting temperature.

(A) Ascorbic acid
(B) Alpha-tocopherol
(C) Beta-carotene
(D) Anthocyanin

2024

291. Which gene was prominently utilized to confer resistance against the broad-spectrum herbicide glyphosate (Roundup) in transgenic crops?
(A) EPSPS gene (CP4 variant)
(B) bar gene
(C) cry1Ac
(D) nptII

2024

292. Nanobiotechnology holds significant promise in modern agriculture. A major applied aspect of nano-agriculture involves:
(A) Creating macroscopic robots
(B) Eliminating the need for photosynthesis
(C) Replacing soil with silicon wafers
(D) Developing nano-encapsulated "smart" fertilizers for targeted, slow release of nutrients

2016

293. The first commercially approved genetically modified whole food was the Flavr Savr tomato. Its primary engineered trait was delayed ripening, achieved via:
(A) Overexpression of ethylene
(B) Antisense suppression of the polygalacturonase gene
(C) Introduction of an insect resistance gene
(D) Mutagenesis using radiation

2015

294. Bio-chips and DNA microarrays applied in agricultural diagnostics allow for:
(A) Instantaneous harvest prediction
(B) Splicing plant genes mechanically
(C) High-throughput simultaneous detection of multiple plant pathogens in a single assay
(D) Generating synthetic plants

2025

295. Which selectable marker gene, conferring resistance to kanamycin, is most widely employed in the initial selection of transgenic plant tissues?
(A) hpt (Hygromycin phosphotransferase)
(B) pat (Phosphinothricin acetyltransferase)
(C) uidA (GUS)
(D) nptII (Neomycin phosphotransferase II)

2005

296. Gene silencing strategies, such as RNAi, have been commercially utilized to engineer crops resistant to:
(A) Specific plant viruses, such as the Papaya Ringspot Virus
(B) Herbicides
(C) Freezing temperatures
(D) Drought

2006

297. The term "pharming" (molecular farming) refers specifically to:
(A) Organic farming practices
(B) Using transgenic plants or animals as bioreactors to produce high-value pharmaceutical proteins
(C) Developing bio-pesticides
(D) Enhancing the nutritional profile of forage crops

NODIA

2025

298. Agrobacterium tumefaciens induces crown gall disease by transferring a segment of DNA. To use it as a safe transformation vector, researchers must first:
(A) Remove the origin of replication
(B) "Disarm" the Ti plasmid by deleting the oncogenes (auxin and cytokinin synthesis genes)
(C) Add a viral envelope
(D) Delete the virulence (vir) genes

2006

299. In plant tissue culture, the totipotency of plant cells is fundamentally exploited to:
(A) Regenerate an entire fertile plant from a single genetically modified somatic cell
(B) Sequence the genome
(C) Extract secondary metabolites
(D) Produce isolated enzymes

2025

300. The application of nanobiosensors in precision agriculture is primarily aimed at:
(A) Increasing tractor speed
(B) Replacing natural sunlight with artificial nano-light
(C) Real-time monitoring of soil conditions, moisture, and crop health parameters
(D) Synthesizing water from atmospheric gases

****

2013

279. The E-value (Expect value) in a BLAST search output indicates:
(A) The exact percentage of identical matches
(B) The length of the alignment
(C) The number of gaps
(D) The expected number of random hits with a score equal to or better than the observed score

2024

280. When designing PCR primers, which parameter is generally targeted to ensure specific and stable annealing to the template?
(A) GC content around 40-60%
(B) Length of 50-100 bases
(C) Tm difference $> 10°C$ between forward and reverse primers
(D) Poly-G tracts at the 3' end

2003

281. Simple primer dimers often appear as low molecular weight artifacts on an agarose gel. They primarily result from:
(A) Primers annealing to multiple template sites
(B) Complementarity between the 3' ends of the forward and reverse primers
(C) Too high an extension temperature
(D) Insufficient Taq polymerase

2016

282. The UPGMA algorithm used in phylogenetic analysis is classified as a:
(A) Character-based method
(B) Distance-matrix method
(C) Maximum likelihood method
(D) Bayesian inference method

2011

283. Unlike UPGMA, the Neighbor-Joining (NJ) method for phylogenetic tree construction is advantageous because it:
(A) Does not assume an equal rate of evolution across all lineages
(B) Forces a constant molecular clock hypothesis
(C) Generates an unrooted tree lacking branch lengths
(D) Only compares protein sequences

2022

284. A clade in a phylogenetic tree represents a monophyletic group, which is defined as:
(A) An ancestor and some of its descendants
(B) Descendants from multiple unrelated ancestors
(C) An ancestor and all of its descendants
(D) Only the extant terminal nodes

2022

285. Multiple sequence alignments (MSA) are critical for identifying conserved domains. A widely used heuristic program for MSA is:
(A) Primer3
(B) RasMol
(C) FASTA
(D) Clustal Omega

2023

286. Homologous genes that arise through speciation events are termed orthologs. Conversely, homologous genes that arise through gene duplication events within a single genome are termed:
(A) Analogs
(B) Xenologs
(C) Paralogs
(D) Pseudogenes

2015

287. Which bioinformatics format represents nucleotide or peptide sequences as simple text starting with a ">" symbol followed by the identifier and sequence?
(A) GenBank format
(B) FASTA format
(C) PDB format
(D) GFF format

2019

288. Bootstrapping is a statistical technique frequently applied to phylogenetic trees. Its primary purpose is to:
(A) Estimate the age of divergence
(B) Align the sequences
(C) Calculate distance matrices
(D) Assess the confidence or reliability of specific clades within the tree

2002

289. In agricultural biotechnology, the development of Bt-cotton involved the transgenic integration of genes from which organism to confer insect resistance?
(A) Bacillus thuringiensis
(B) Agrobacterium tumefaciens
(C) Escherichia coli
(D) Arabidopsis thaliana

2018

290. Golden Rice was genetically engineered to combat vitamin A deficiency. It achieves this by expressing the biosynthetic pathway for:

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10. (A) Both A and R are true and R is the correct explanation of A.
Z-DNA is a left-handed helical form of DNA that is favored by sequences with alternating purines and pyrimidines. The zig-zag shape of the backbone arises because the purine residues adopt a syn glycosidic bond conformation while the pyrimidine residues maintain the anti conformation. This structural alternating arrangement is the fundamental reason why these specific sequences can form the helix.

11. (A) Hydrophobic effects and van der Waals forces
The stability of the DNA double helix is maintained by horizontal hydrogen bonding between complementary bases and vertical stacking interactions. These vertical forces are primarily driven by hydrophobic effects that exclude water from the interior of the helix and van der Waals attractions between the flat, aromatic rings of adjacent bases. These combined interactions provide significant thermodynamic stabilization.

12. (C) The presence of a 2'-hydroxyl group
Nucleotides are the building blocks of nucleic acids, differing primarily in their sugar component. Ribonucleotides, which form RNA, contain a ribose sugar characterized by the presence of a hydroxyl group at the two-prime carbon position. In contrast, deoxyribonucleotides lack this specific oxygen atom, making the DNA molecule more chemically stable and less susceptible to hydrolysis compared to its RNA counterpart.

13. (D) rRNA
Ribosomal RNA is a fundamental component of the cellular machinery responsible for protein synthesis. It combines with various proteins to form the small and large subunits of the ribosome. Beyond providing a structural scaffold, specific segments of this RNA act as a ribozyme to catalyze the formation of peptide bonds between amino acids during the translation of messenger RNA transcripts.

14. (C) miRNA
MicroRNAs are short, non-coding RNA molecules that play a critical role in the post-transcriptional regulation of gene expression. They function by binding to complementary sequences on target messenger RNAs, typically within the three-prime untranslated region. This binding leads to either the degradation of the transcript or the inhibition of its translation, thereby effectively silencing the expression of specific genes.

15. (B) Cloverleaf
The secondary structure of transfer RNA is formed by internal base pairing, resulting in a distinctive pattern of four arms and three loops. This arrangement resembles a cloverleaf, featuring an acceptor arm, a D-loop, an anticodon loop, and a T-loop. This specific fold is essential for the molecule's role in delivering amino acids to the ribosome during the process of translation.

16. (D) mRNA
In eukaryotic cells, primary RNA transcripts undergo extensive processing before they can be exported to the cytoplasm for translation. Mature messenger RNA molecules are specifically characterized by the addition of a seven-methylguanosine cap at the five-prime end and a long poly-adenosine tail at the three-prime end. These modifications enhance stability and facilitate the recruitment of the translation machinery.

NODIA

17. (A) U1
The splicing of eukaryotic pre-mRNA is mediated by a complex called the spliceosome. The process begins with the recognition of the five-prime splice site by the U1 small nuclear ribonucleoprotein. This specific binding is achieved through complementary base pairing between the U1 snRNA and the conserved sequence at the intron-exon boundary, marking the start of the assembly.

18. (C) Chemical modification of rRNAs
Small nucleolar RNAs are a class of non-coding RNA molecules primarily localized within the nucleolus of eukaryotic cells. Their main biological function is to guide the site-specific chemical modification of ribosomal RNA transcripts. These modifications, such as 2-prime-O-methylation and pseudouridylation, are essential for the proper folding, stability, and functional activity of the mature ribosomes during the translation process.

19. (A) RNA Polymerase II - pre-mRNA
Eukaryotic cells utilize three distinct types of RNA polymerase enzymes to transcribe

(B) RFLP
(C) AFLP
(D) SSR

2005

236. Single Nucleotide Polymorphisms (SNPs) are the most abundant markers in genomes. They represent what type of genetic variation?
(A) Large-scale inversions
(B) Varying numbers of tandem repeats
(C) Single base pair substitutions
(D) Whole chromosome duplications

2004

237. The process of gene isolation via "homology-based cloning" utilizes the assumption that:
(A) All genes have identical promoters.
(B) Introns are highly conserved.
(C) Gene position is conserved in all life forms.
(D) Genes with similar functions share conserved DNA sequence homology across species.

2015

238. In a Southern blot hybridization, the target molecules separated on the gel and detected by the probe are:
(A) Proteins
(B) RNA fragments
(C) DNA fragments
(D) Lipids

2017

239. Northern blotting is specifically designed for the detection and qualitative analysis of:
(A) DNA
(B) RNA
(C) Proteins
(D) Glycoproteins

2004

240. Identify the correct chronological sequence of events in Map-based Gene Isolation:
I. High-resolution fine mapping
II. Identification of linked molecular markers
III. Phenotypic evaluation of mapping population
IV. Complementation test to confirm gene function
Which of the following is the correct chronological sequence?
(A) II, III, I, IV
(B) III, II, I, IV
(C) I, II, III, IV
(D) III, I, II, IV

2008

241. The Sanger method of DNA sequencing relies on the incorporation of chain-terminating nucleotides. What is the distinguishing chemical feature of these molecules?
(A) Absence of a 3'-hydroxyl group
(B) Absence of a 2'-hydroxyl group
(C) Presence of a 3'-phosphate group
(D) Lack of a nitrogenous base

2023

242. In automated Sanger sequencing, each of the four dideoxynucleotides (ddNTPs) is labeled with a distinct:
(A) Radioactive isotope
(B) Magnetic bead
(C) Fluorescent dye
(D) Heavy metal

2011

243. Next-Generation Sequencing (NGS) platforms achieve vastly higher throughput than traditional Sanger sequencing primarily by:
(A) Performing massively parallel sequencing of millions of fragments simultaneously
(B) Utilizing longer reads
(C) Eliminating the need for DNA polymerase
(D) Sequencing directly from whole intact chromosomes

2019

244. The Illumina NGS platform determines the DNA sequence by utilizing which specific core technology?
(A) Sequencing by ligation
(B) Detection of pH changes during nucleotide incorporation
(C) Nanopore electrical disruption
(D) Sequencing by synthesis with reversible terminators

2006

245. Which NGS technology detects the sequence by measuring the release of hydrogen ions (pH change) as nucleotides are incorporated?
(A) Pacific Biosciences
(B) Ion Torrent
(C) Illumina
(D) Pyrosequencing

2002

246. The Edman degradation method is classically used for the sequence analysis of:
(A) Double-stranded DNA
(B) Small RNAs
(C) Peptide chains (Proteins)

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29. (D) Writhe
The topological state of a closed-circular DNA molecule is described by the linking number equation. In this formula, the linking number equals the sum of the twist and the writhe. The twist refers to the number of times the two strands cross each other, while the writhe represents the number of times the double helix axis crosses itself.

30. (C) II
DNA supercoiling is a critical aspect of genome architecture. Most natural DNA is maintained in a negatively supercoiled state, which facilitates the unwinding of the helix. While positive supercoiling overwinds the helix, DNA gyrase is a unique bacterial enzyme that actually introduces negative supercoils, not positive ones. This activity is essential for relieving the stress generated during replication.

31. (B) Binds to linker DNA to stabilize higher-order structures
Histone H1 is known as the linker histone because it associates with the DNA that connects adjacent nucleosome core particles. By binding to both the linker DNA and the nucleosome core, H1 facilitates the folding of the beads-on-a-string fiber into a more compact thirty-nanometer chromatin fiber. This role is essential for achieving high levels of chromosomal condensation.

32. (B) 30 nm
The organization of chromatin follows a hierarchical structure to fit within the nucleus. The primary ten-nanometer fiber, consisting of nucleosomes connected by linker DNA, undergoes further compaction. With the assistance of linker histones like H1, this fiber coils into a more complex solenoid or zig-zag structure with a diameter of approximately thirty nanometers. This represents the second level.

33. (A) Transcriptionally inactive and tightly condensed
Chromatin exists in two main functional states within the eukaryotic nucleus. Heterochromatin represents the regions of the genome that are highly condensed and densely stained. Because of this tight packaging, the underlying DNA sequences are generally inaccessible to the transcription machinery, including RNA polymerase. Consequently, heterochromatin is associated with gene silencing and remains transcriptionally inactive throughout most cycles.

34. (C) Centromere
Successful cell division requires the precise distribution of replicated chromosomes to daughter cells. This process depends on a specialized region of the chromosome characterized by unique chromatin structures. This region serves as the assembly site for the kinetochore, which mediates the attachment of spindle microtubules. Proper segregation is impossible without this structural anchor point during mitosis or meiosis.

35. (A) Type II
DNA gyrase is a fundamental bacterial enzyme that manages the topological state of the circular chromosome. It belongs to the class of type two topoisomerases because it functions by creating a transient double-strand break in the DNA. Unlike most other enzymes in its class, gyrase is unique because it can actively use ATP energy to introduce negative supercoils.

NODIA

36. (D) Alpha-helices rich in basic amino acids
Histone proteins have evolved to bind DNA with high affinity and low sequence specificity. They achieve this through the presence of structural domains called histone folds, which consist of multiple alpha-helices. These helices are rich in positively charged basic amino acids like lysine and arginine. These positive residues form electrostatic interactions with the negatively charged phosphate backbone groups.

37. (B) DNA Polymerase III
In the bacterium Escherichia coli, several DNA polymerases perform different roles in genome maintenance. While DNA polymerase one is involved in primer removal and repair, DNA polymerase three is the primary replicative enzyme. It possesses high processivity and a rapid rate of nucleotide incorporation, allowing it to synthesize the vast majority of both the leading and lagging strands.

38. (C) Leading strand
DNA replication is described as semi-discontinuous because the two strands of the double helix are anti-parallel, while DNA polymerase can only synthesize in the five-prime to three-prime direction. The strand

98. (C) Shine-Dalgarno sequence
In bacteria, the initiation of translation requires the precise positioning of the small ribosomal subunit on the messenger RNA. This is achieved through the recognition of a purine-rich sequence located a few nucleotides upstream of the start codon. Known as the Shine-Dalgarno sequence, it base-pairs with a complementary sequence at the three-prime end of the sixteen-S ribosomal RNA.

99. (A) ATP
The process of attaching an amino acid to its transfer RNA molecule is an endergonic reaction that requires an input of chemical energy. This energy is provided by the hydrolysis of ATP to AMP and inorganic pyrophosphate. The reaction occurs in two steps within the aminoacyl-tRNA synthetase enzyme, resulting in an activated amino acid ready for peptide formation.

100. (A) I, II and III
Translation elongation is a cycle of three steps. First, an elongation factor called EF-Tu brings the correct aminoacyl-tRNA to the A site. Then, the ribosomal RNA catalyzes the formation of a peptide bond. Finally, the ribosome translocates, moving the uncharged tRNA to the E site for exit. Notably, this translocation step is powered by the hydrolysis of GTP.

101. (B) The large ribosomal subunit RNA
For many years, it was assumed that proteins in the ribosome catalyzed the formation of the peptide bond. However, structural and biochemical evidence has revealed that the peptidyl transferase center is composed entirely of ribosomal RNA from the large subunit. This makes the ribosome a ribozyme, where the RNA itself provides the chemical environment and catalysis necessary for synthesis.

102. (B) Kozak consensus sequence
In eukaryotic translation, the small ribosomal subunit initially binds to the five-prime cap and then scans along the messenger RNA until it encounters the first A-U-G codon. The efficiency of initiation is enhanced if this start codon is embedded within a specific surrounding sequence. This consensus sequence, known as the Kozak sequence, helps the ribosome identify the start.

103. (D) A site
The ribosome contains three distinct binding sites for transfer RNA: the aminoacyl (A) site, the peptidyl (P) site, and the exit (E) site. During the elongation phase of protein synthesis, each new incoming aminoacyl-tRNA, which carries the next amino acid to be added to the chain, enters the ribosome at the A site after delivery by elongation factors.

104. (A) RF1
When a ribosome encounters a stop codon, it pauses because there are no transfer RNAs with matching anticodons. Instead, specialized proteins called release factors enter the A site. In bacteria, there are two main release factors with different specificities. RF1 is the factor that specifically recognizes the U-A-A and U-A-G stop codons, triggering the hydrolysis of the polypeptide.

105. (C) A is true but R is false.
In bacteria, translation always begins with a modified form of methionine called N-formylmethionine. While it is true that this is the first amino acid incorporated, the reason provided is incorrect. The formyl group is not used for protection against degradation. Instead, it is required for the specific recognition of the initiator tRNA by the initiation factor IF-2 during assembly.

106. (C) Three
Translocation is the step in translation where the ribosome moves forward along the messenger RNA after a peptide bond has been formed. To maintain the correct reading frame and ensure that the next codon is positioned in the A site, the ribosome must move exactly three nucleotides. This distance corresponds to one full codon, allowing accurate polypeptide synthesis.

107. (A) EF-G
The movement of the ribosome along the messenger RNA is an active process that requires a specialized elongation factor. In prokaryotes, this factor is EF-G, also known as translocase. EF-G binds to the ribosome and uses the energy from GTP hydrolysis to drive the physical shift of the transfer RNAs and the messenger RNA, moving the growing chain.

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DNA polymerase alpha is unique because it is associated with a primase subunit. This complex first synthesizes a short RNA primer and then extends it with a brief segment of DNA. This hybrid primer then serves as the starting point.

49. (A) To protect chromosomal ends from degradation and fusion
Telomeres are specialized nucleoprotein complexes found at the termini of linear eukaryotic chromosomes. They consist of repetitive DNA sequences and specific binding proteins. Their primary biological function is to act as protective caps. By distinguishing the natural ends of chromosomes from double-strand breaks, they prevent DNA repair machinery from causing inappropriate chromosomal fusions or triggering massive nucleolytic degradation.

50. (D) I, III and IV
Telomerase is a unique enzyme that counteracts the shortening of chromosomes. It is a ribonucleoprotein, meaning it contains both a protein component and an internal RNA molecule that serves as a template for DNA synthesis. Because it synthesizes DNA from an RNA template, it functions as a reverse transcriptase. It specifically extends the three-prime ends of chromosomes.

51. (A) Linear eukaryotic chromosomes
The end-replication problem is a consequence of the requirement for RNA primers and the directional nature of DNA polymerase. During the replication of linear DNA molecules, the removal of the final RNA primer at the extreme five-prime end of the lagging strand leaves a gap that cannot be filled. This leads to progressive shortening of the DNA.

52. (D) RNA-dependent DNA polymerase
Telomerase is categorized as an RNA-dependent DNA polymerase because its catalytic mechanism involves using an integral RNA sequence as a guide for synthesizing DNA. This specific activity allows the enzyme to add repetitive nucleotide sequences to the ends of chromosomes. This process is essentially the reverse of transcription, similar to the mechanism used by retroviruses to replicate their genomes.

53. (B) TTAGGG
The DNA sequence of telomeres is highly conserved across various taxonomic groups. In most vertebrates, including humans, the telomeric regions consist of hundreds to thousands of tandem repeats of the hexanucleotide sequence T-T-A-G-G-G. This G-rich strand always forms the three-prime overhang, which is essential for the binding of specialized protection proteins and the activity of telomerase.

NODIA

54. (C) Their chromosomes are circular.
The end-replication problem specifically affects the termini of linear DNA molecules where the last RNA primer cannot be replaced by DNA. Most prokaryotic organisms, such as bacteria, possess circular chromosomes. Because a circle has no ends, the replication forks eventually meet and the entire molecule is replicated without any loss of sequence. Consequently, these organisms do not require telomerase.

55. (A) P-2, Q-4, R-1, S-3
Eukaryotic DNA replication involves several specialized proteins. DNA polymerase delta is the primary enzyme for lagging strand synthesis. The removal of RNA primers requires flap endonuclease one. Mitochondrial DNA is replicated independently by DNA polymerase gamma. To ensure high processivity, these polymerases associate with PCNA, a sliding clamp protein that circles the DNA and prevents enzyme dissociation.

56. (A) T-loop
To prevent the ends of linear chromosomes from being recognized as damaged DNA, the single-stranded three-prime overhang of the telomere undergoes a unique structural rearrangement. It loops back and invades the upstream double-stranded telomeric DNA, creating a structure known as a T-loop. This configuration effectively hides the chromosome end, protecting it from degradation and preventing the activation of responses.

57. (B) Replicative senescence
In most human somatic cells, telomerase is not expressed, leading to the progressive loss of telomeric DNA with every round of replication. Once the telomeres reach a critically short length, they can no longer protect the chromosome ends. This triggers a permanent exit from the cell cycle known as replicative senescence, which acts as a barrier against cancer.

58. (B) Origin recognition complex (ORC)
Eukaryotic DNA replication is tightly regulated and must begin at specific sites called origins. These origins are identified by the origin recognition complex, a conserved six-subunit protein assembly. The complex binds to the origin DNA throughout the majority of the cell cycle and serves as the fundamental scaffold for recruiting other initiation factors that load the replicative helicases.

59. (A) It is slower in eukaryotes due to chromatin structure.
The rate of DNA replication differs significantly between domains of life. In prokaryotes, the replication fork moves very rapidly through the relatively naked DNA. In eukaryotes, the progression is much slower. This reduction in speed is primarily because the replication machinery must contend with the complex packaging of DNA into nucleosomes and higher-order chromatin structures during synthesis.

60. (B) I, III, IV, II
The initiation of eukaryotic DNA replication follows a strict temporal order to ensure the genome is replicated only once. First, the origin recognition complex binds to the DNA. Then, recruitment factors like Cdc6 and Cdt1 are brought to the site. These factors facilitate the loading of the MCM helicase complex. Finally, at S-phase, the helicase is activated.

61. (D) Sigma
In bacteria, the RNA polymerase core enzyme is capable of synthesizing RNA but cannot identify where to start. Specificity is provided by the sigma factor subunit, which associates with the core to form the holoenzyme. The sigma factor directly recognizes and binds to conserved promoter sequences upstream of the gene, ensuring that transcription begins at the correct site.

62. (C) Pribnow box
Prokaryotic promoters are characterized by two highly conserved consensus sequences located upstream of the transcription start site. The element found approximately ten nucleotides upstream is a six-base sequence typically consisting of T-A-T-A-A-T. Commonly referred to as the Pribnow box, this region is essential for the initial binding of RNA polymerase and the melting of the DNA helix.

63. (B) Elongation
Transcription in prokaryotes is divided into initiation, elongation, and termination phases. During initiation, the sigma factor is required to guide the RNA polymerase to the promoter. Once a short segment of RNA has been successfully synthesized and the polymerase has cleared the promoter to enter the elongation phase, the sigma factor dissociates from the core enzyme for recycling.

64. (D) TFIID
RNA polymerase two requires a set of general transcription factors to initiate transcription at eukaryotic promoters. The first factor to bind is TFIID, which is a large multi-protein complex. A key component of this complex is the TATA-binding protein, which directly recognizes and bends the TATA box DNA. This binding event serves as the foundation for assembly.

65. (A) They can increase transcription levels from a great distance.
Enhancers are powerful regulatory DNA sequences that significantly increase the rate of transcription of specific genes. A defining characteristic of enhancers is their flexibility; they can function effectively regardless of their orientation and can be located thousands of base pairs away from the promoter. They work by looping the DNA to bring distant transcription factors to the promoter.

66. (C) A GC-rich hairpin loop followed by a poly-U tract
In bacteria, some genes utilize an intrinsic termination mechanism that does not require the Rho protein. This process depends on a specific sequence at the end of the gene that forms a stable, GC-rich hairpin structure in the nascent RNA. This is immediately followed by a string of uracil residues. This combination causes the polymerase to stall and dissociate.

67. (A) TFIIH
Among the general transcription factors, TFIIH plays a unique and essential role in the transition from initiation to elongation. It possesses ATP-dependent helicase activity that unwinds the DNA to form the transcription bubble. Additionally, it contains a kinase subunit that phosphorylates the carboxy-terminal domain of RNA polymerase two. This chemical modification is the signal for promoter clearance.

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68. (D) RNA Polymerase II
Alpha-amanitin is a toxic cyclic peptide produced by certain mushrooms that interferes with the transcriptional machinery. While eukaryotic cells contain multiple RNA polymerases, they show varying degrees of sensitivity to this toxin. RNA polymerase two is extremely sensitive, being inhibited at very low concentrations. This inhibition blocks the translocation of the enzyme along the DNA, halting mRNA synthesis.

69. (B) Chromatin remodeling
Transcription in eukaryotic cells is significantly more complex than in prokaryotes because the genomic DNA is tightly packaged into chromatin. To allow RNA polymerase and transcription factors access to the gene, the chromatin structure must be actively modified. This involves the use of ATP-dependent remodeling complexes and histone-modifying enzymes to loosen the nucleosomes, which is essential for initiation.

70. (A) Both A and R are true and R is the correct explanation of A.
In prokaryotic organisms, the lack of a defined nucleus means that there is no physical barrier between the genomic DNA and the cytoplasm. As a result, ribosomes can begin translating the five-prime end of a messenger RNA molecule while the three-prime end is still being synthesized by RNA polymerase. This coupling allows for rapid cellular response to changes.

71. (C) -70 to -80
Eukaryotic promoters often contain several conserved regulatory elements upstream of the transcription start site that influence the efficiency of initiation. One such element is the CAAT box, which typically has the consensus sequence G-G-C-C-A-A-T-C-T. This sequence is generally located between seventy and eighty base pairs upstream of the start site and serves as a factor binding site.

72. (A) TFIIF
The assembly of the eukaryotic pre-initiation complex is a highly coordinated process. After TFIID and TFIIB have bound to the promoter, the RNA polymerase two enzyme must be brought to the site. This recruitment is primarily the function of TFIIF, which binds directly to the polymerase and guides it into the complex. This interaction ensures correct enzyme positioning.

73. (B) 7-methylguanosine
Very shortly after the initiation of transcription in eukaryotes, the nascent pre-messenger RNA undergoes a critical modification at its five-prime end. A guanine nucleotide is added in a reverse orientation and is subsequently methylated at the seven-position of the purine ring. This seven-methylguanosine cap is essential for protecting the transcript from exonucleases and for ribosome recognition.

74. (B) 5',5'-triphosphate linkage
The five-prime cap of eukaryotic messenger RNA is attached via a unique chemical bond that is not found elsewhere in nucleic acids. Instead of the standard three-prime to five-prime phosphodiester bond, the seven-methylguanosine nucleotide is joined to the first nucleotide of the transcript through a five-prime to five-prime triphosphate bridge. This unusual orientation makes the cap resistant to degradation.

75. (A) Both A and R are true and R is the correct explanation of A.
The poly-adenosine tail at the three-prime end of eukaryotic messenger RNA is a post-transcriptional modification. Unlike the rest of the RNA sequence, these adenine residues are not encoded by the DNA template. Instead, after the transcript is cleaved, an enzyme called poly-A polymerase adds approximately two hundred adenine nucleotides sequentially. This process is entirely template-independent.

76. (C) Adenine
Splicing of nuclear pre-mRNA involves two sequential transesterification reactions. The first reaction is initiated when the two-prime hydroxyl group of a specific, highly conserved adenine nucleotide within the intron attacks the five-prime splice site. This adenine is located at the branch point sequence. This nucleophilic attack results in the formation of a branched lariat structure, marking the process.

77. (D) Lariat
During the process of pre-messenger RNA splicing, the intron is removed in a specific two-step chemical reaction. The result of these transesterification steps is the excision of the intervening sequence in the form of a looped structure. This shape, which looks like a lasso, is formed by a covalent bond between the five-prime end of the intron and the branch point.

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78. (C) GU
The boundaries between exons and introns are defined by highly conserved consensus sequences that are recognized by the splicing machinery. In the vast majority of eukaryotic genes, the intron begins with the dinucleotide G-U at its five-prime end, which is known as the donor site. This sequence is essential for the correct identification and cleavage by the sliceosome complex.

79. (B) snRNAs
The spliceosome is a massive macromolecular complex responsible for the precise removal of introns from pre-messenger RNA. It is composed of five specialized small nuclear ribonucleoprotein particles. Each of these particles contains a specific small nuclear RNA molecule that plays a direct role in recognizing splice sites and catalyzing the transesterification reactions. These RNAs provide both structure and activity.

80. (A) P-2, Q-4, R-1, S-3
Post-transcriptional processing involves several key elements. The U1 snRNP recognizes and binds the donor site, while the U2 snRNP binds to the internal branch point. The poly-adenylation signal sequence, A-A-U-A-A-A, marks the site for transcript cleavage and tail addition. Meanwhile, the five-prime cap is essential for the recruitment of the ribosome to the mRNA during translation.

81. (A) AAUAAA
The three-prime end of most eukaryotic messenger RNAs is generated by a precise cleavage and poly-adenylation event. This process is initiated when the cleavage and poly-adenylation specificity factor recognizes a highly conserved hexanucleotide sequence, A-A-U-A-A-A, located upstream of the cleavage site. Binding to this signal is the first essential step in recruiting the machinery that adds the tail.

82. (C) Produce multiple protein isoforms from a single gene
Alternative splicing is a sophisticated regulatory mechanism that allows the cell to expand its protein diversity without increasing its genome size. By selectively including or excluding different exons from the primary transcript, a single gene can produce multiple distinct messenger RNA variants. Each variant is then translated into a different protein isoform with potentially unique functional properties.

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83. (A) Free guanine nucleotide
Group one introns are a class of self-splicing RNAs that do not require a spliceosome to be removed. Instead, they utilize an intrinsic catalytic activity. The splicing process is initiated by a free guanosine or guanine nucleotide cofactor. This nucleotide binds to a specific site in the intron and its three-prime hydroxyl group performs the first nucleophilic attack.

84. (D) 5' Capping
The five-prime cap of eukaryotic messenger RNA is a critical modification for ensuring the longevity of the transcript. Most cellular exonucleases degrade RNA in a five-prime to three-prime direction by recognizing free five-prime ends. By masking this end with a seven-methylguanosine residue attached via an unusual linkage, the cap effectively blocks these enzymes, increasing the mRNA half-life.

85. (B) Multiple codons can specify the same amino acid
The genetic code consists of sixty-four possible three-nucleotide codons, but there are only twenty standard amino acids. This redundancy is known as degeneracy. Most amino acids are encoded by more than one codon, which provides a level of protection against mutations. For example, a single base change at the third position of a codon often results in the same amino acid.

86. (C) AUG
Translation of a messenger RNA sequence into a polypeptide always begins at a specific site. In almost all organisms and across both nuclear and organellar genomes, the three-nucleotide sequence A-U-G serves as the universal start codon. This codon establishes the correct reading frame for the ribosome and typically specifies the incorporation of the amino acid methionine at the start.

87. (C) 3
Among the sixty-four possible codons in the standard genetic code, sixty-one code for specific amino acids. The remaining three codons do not specify an amino acid and instead act as signals for the ribosome to stop translation. These stop codons, namely U-A-A, U-A-G, and U-G-A, are recognized by release factors that trigger the liberation of the polypeptide.

88. (A) The third position (3' end)
The wobble hypothesis explains how a single transfer RNA molecule can recognize multiple different codons. While the first two positions of the codon-anticodon interaction follow strict Watson-Crick base pairing rules, the third position at the three-prime end of the codon is more flexible. This "wobble" allows for non-standard pairing, reducing the minimum number of tRNA types required.

89. (B) Tryptophan
While most amino acids are represented by multiple codons due to the degeneracy of the genetic code, there are two notable exceptions. Methionine and tryptophan are each encoded by only a single specific codon. For tryptophan, the unique codon is U-G-G. This lack of redundancy makes genes particularly sensitive to mutations in these codons, as any change results in a different residue.

90. (B) II and III
The genetic code has several fundamental properties that ensure accurate translation. It is non-overlapping, meaning each nucleotide is part of only one codon. It is also comma-less, meaning the sequence is read continuously without pauses. While it is nearly universal, several exceptions have been discovered in mitochondria and some protozoa, meaning it is not strictly identical across all life.

91. (A) Ochre codon
The three termination codons were given names based on the phenotypes of the bacterial mutants in which they were first studied. The U-A-A codon is historically known as the ochre codon. Similarly, U-A-G is referred to as amber and U-G-A is known as opal. These terms are still commonly used in molecular biology to describe nonsense mutations that cause termination.

92. (C) Tryptophan
Although the genetic code is nearly universal, several organisms and organellar genomes have evolved slight variations. In vertebrate mitochondria, the codon U-G-A, which normally serves as a termination signal in the standard code, is reassigned to encode the amino acid tryptophan. This represents one of the most common deviations and highlights the independent evolutionary history of mitochondrial genomes.

93. (D) Insertion of a single nucleotide
A frameshift mutation occurs when the addition or deletion of nucleotides shifts the triplet reading frame of the messenger RNA. Because the code is read in groups of three without overlap, any insertion or deletion that is not a multiple of three will change every subsequent codon. This usually results in a completely different amino acid sequence and premature stop.

94. (C) Inosine
Inosine is a modified purine base often found at the first position of the anticodon in transfer RNA, which corresponds to the third or wobble position of the codon. Due to its unique chemical structure, inosine can form hydrogen bonds with uracil, cytosine, and adenine. This versatility allows a single tRNA to recognize three different codons, contributing to translational efficiency.

95. (B) A specific codon designates only one particular amino acid
The genetic code is characterized by two distinct properties: degeneracy and unambiguity. While degeneracy means multiple codons can code for the same amino acid, being unambiguous means that each individual codon always specifies exactly one amino acid. This ensures that the translation of a specific genetic sequence will always produce a consistent and predictable protein product without chemical uncertainty.

96. (D) UGA
Selenocysteine is often referred to as the twenty-first amino acid because it is incorporated directly into proteins during translation. It is encoded by the U-G-A codon, which normally acts as a stop signal. Its incorporation requires a specific hairpin structure in the messenger RNA known as a SECIS element, which recruits specialized factors that cause a read-through.

97. (A) Aminoacyl-tRNA synthetases
The accuracy of protein synthesis depends on the correct pairing of amino acids with their corresponding transfer RNA molecules. This charging process is performed by a class of enzymes called aminoacyl-tRNA synthetases. Each enzyme is specific for one amino acid and its cognate tRNAs, using the energy of ATP to create a high-energy ester bond between the components.

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that is synthesized in the same direction as the moving replication fork can be produced as one continuous piece. This efficiently synthesized DNA segment is the leading strand.

39. (D) To synthesize a short RNA primer
DNA polymerases are unable to initiate the synthesis of a new DNA chain from scratch; they require a free three-prime hydroxyl group to add nucleotides. Primase is a specialized RNA polymerase that solves this problem by synthesizing a short segment of RNA complementary to the template. This RNA primer provides the necessary starting point for DNA replication.

40. (A) I, II and III
DNA ligase is an essential enzyme for maintaining genomic integrity during replication and repair. It functions by catalyzing the formation of a phosphodiester bond between a three-prime hydroxyl and a five-prime phosphate at a single-strand nick. This reaction requires chemical energy from ATP or NAD. Its primary role in replication is to join the Okazaki fragments produced.

41. (B) 5' to 3' exonuclease activity
DNA polymerase one is a multi-functional enzyme with several distinct activities. Unlike the primary replicative polymerase, it possesses a unique five-prime to three-prime exonuclease activity. This allows the enzyme to move along the DNA and degrade RNA primers encountered in its path. Simultaneously, its polymerase activity fills the resulting gap with DNA nucleotides, ensuring a continuous strand.

42. (B) DNA Helicase
The replication of the genetic material requires the separation of the two complementary strands of the parental double helix. DNA helicase is the motor protein responsible for this task. It binds to the DNA at the replication fork and uses energy derived from ATP hydrolysis to break the hydrogen bonds between the base pairs, thereby unwinding the helix.

43. (A) Okazaki fragments
Because DNA polymerase can only synthesize in a five-prime to three-prime direction, the lagging strand template must be replicated in a direction opposite to the movement of the replication fork. This results in the synthesis of many short, discrete segments of DNA. These segments, which are later joined together by DNA ligase, are named after the discovering scientist.

44. (C) Single-strand binding proteins (SSBs)
Once DNA helicase unwinds the parental double helix, the resulting single strands are inherently unstable and have a high tendency to re-anneal or form secondary structures. Single-strand binding proteins rapidly coat these exposed strands. By binding to the DNA, they prevent the strands from coming back together and protect them from degradation, keeping the template accessible for synthesis.

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45. (A) Both A and R are true and R is the correct explanation of A.
All known DNA polymerases share a fundamental biochemical constraint: they can only catalyze the addition of a new nucleotide to an existing three-prime hydroxyl group. This requires that the new strand always grows in a five-prime to three-prime direction. This chemical necessity explains why replication is a directional process and why the lagging strand must be synthesized fragments.

46. (C) DNA Polymerase I
Although DNA polymerase three performs the bulk of DNA synthesis in Escherichia coli, DNA polymerase one is vital for completing the process. Its unique combination of five-prime to three-prime exonuclease and polymerase activities makes it perfectly suited for removing RNA primers and filling the resulting gaps with DNA. It also plays a major role in various repair pathways.

47. (B) 3' to 5' exonuclease
High-fidelity DNA replication is essential for preventing the accumulation of mutations. Replicative DNA polymerases possess an intrinsic proofreading mechanism mediated by three-prime to five-prime exonuclease activity. If an incorrect nucleotide is incorporated, the polymerase pauses, moves backward to remove the mismatched base using this activity, and then resumes correct five-prime to three-prime synthesis, significantly reducing the error rate.

48. (D) Polymerase alpha
In eukaryotic cells, the initiation of DNA synthesis at each origin of replication is a complex process involving multiple polymerases.

108. (C) Chloramphenicol
Many antibiotics work by selectively targeting the bacterial ribosome, which differs structurally from the eukaryotic version. Chloramphenicol is a broad-spectrum antibiotic that binds to the fifty-S large ribosomal subunit. By doing so, it directly inhibits the peptidyl transferase activity of the ribosomal RNA, preventing the formation of peptide bonds and effectively halting protein synthesis in the bacterial cell.

109. (D) Prenylation
Post-translational modifications are essential for expanding the functional range of proteins. Some proteins must be anchored to the cell membrane to perform their functions. Prenylation is a specific modification where a lipid group, such as a farnesyl or geranylgeranyl isoprenoid, is covalently attached to a cysteine residue. This lipid anchor increases hydrophobicity, allowing the protein to insert into membranes.

110. (C) III
Ubiquitination is a highly regulated process that marks proteins for degradation by the twenty-six-S proteasome. It involves the sequential action of three enzymes: E1 (activating), E2 (conjugating), and E3 (ligase). Statement three is incorrect because it falsely suggests only one enzyme is required. E3 is particularly important as it provides the specificity for selecting the target protein for degradation.

111. (B) Serine, threonine, and tyrosine
Phosphorylation is perhaps the most common reversible post-translational modification used to regulate protein activity. It involves the addition of a phosphate group from ATP to a specific amino acid side chain. This modification occurs almost exclusively on the hydroxyl groups of three amino acids: serine, threonine, and tyrosine. The resulting negative charge can cause conformational changes that activate proteins.

112. (D) N-linked glycosylation
Glycosylation is the process of attaching carbohydrate chains to proteins, which is vital for proper folding and cell signaling. When the oligosaccharide is attached to the nitrogen atom of the amide group on an asparagine side chain, it is called N-linked glycosylation. This process begins in the endoplasmic reticulum and is characterized by a specific consensus sequence on the target.

113. (A) Preventing inappropriate hydrophobic interactions
Although the primary sequence of a protein contains all the information needed for folding, many proteins require assistance to reach their native state efficiently. Molecular chaperones provide this help by binding to exposed hydrophobic regions of nascent or partially unfolded polypeptides. By shielding these regions, chaperones prevent the proteins from aggregating into non-functional clumps, allowing them to fold correctly.

114. (C) Chaperonins
Chaperonins are a specific family of molecular chaperones that provide a protected internal environment for protein folding. In bacteria, the most well-studied example is the GroEL-GroES complex. This barrel-shaped structure captures unfolded proteins inside its central cavity, away from the crowded cytoplasm. Using ATP, the chaperonin system facilitates the folding process until the protein reaches its correct final three-dimensional conformation.

115. (A) P-2, Q-1, R-4, S-3
Various enzymes control protein function through post-translational modifications. Kinases add phosphate groups to regulate activity, while phosphatases remove them. Ubiquitin ligases are responsible for attaching the ubiquitin tag that signals a protein should be degraded. Finally, signal peptidases are specialized enzymes that cleave off the targeting sequence once a protein has successfully reached its correct final cellular destination.

116. (D) N-terminus
Proteins that are destined for the secretory pathway or for specific organelles often contain a built-in targeting signal. For secreted proteins, this is typically a short signal peptide located at the amino terminus. This sequence is synthesized first by the ribosome and is recognized by the cellular machinery that directs the protein to the membrane of the endoplasmic reticulum for translocation.

117. (B) Endoplasmic reticulum
The signal recognition particle is a ribonucleoprotein that plays a central role in protein targeting. It recognizes and binds to the signal peptide as it emerges from the ribosome. This binding causes a temporary pause in

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translation and allows the entire ribosome-nascent chain complex to be delivered to the membrane of the endoplasmic reticulum, where synthesis is then completed.

118. (C) Endoplasmic reticulum lumen
Disulfide bonds are covalent linkages between the sulfur atoms of two cysteine residues that stabilize the three-dimensional structure of many proteins. These bonds generally do not form in the reducing environment of the cytosol. Instead, they are formed in the more oxidizing environment of the endoplasmic reticulum lumen, catalyzed by enzymes such as protein disulfide isomerase as the proteins fold.

119. (D) Palmitoylation
Palmitoylation is a post-translational modification involving the covalent attachment of a sixteen-carbon saturated fatty acid to specific cysteine residues. Unlike some other lipid modifications, palmitoylation is often reversible. This modification increases the membrane affinity of a protein, allowing it to be dynamically recruited to the plasma membrane or internal membranes, which is essential for many different signaling and trafficking processes.

120. (A) II, III, I, IV
N-linked glycosylation is a multi-step process. It starts with the assembly of a precursor oligosaccharide on a dolichol phosphate carrier in the endoplasmic reticulum membrane. This entire carbohydrate block is then transferred to an asparagine residue on a protein. Subsequently, the sugar chain is trimmed, including the removal of glucose residues, before the protein is transported to the Golgi.

121. (B) Negative inducible
The lac operon is a classic model for gene regulation. It is considered a negative system because a repressor protein normally binds to the operator to block transcription. It is inducible because the presence of lactose causes the repressor to detach, thereby "inducing" the expression of the genes. This mechanism ensures that the enzymes for lactose metabolism are produced only.

122. (B) Beta-galactosidase
The lac operon contains three structural genes required for the utilization of lactose. The first gene, lacZ, encodes the enzyme beta-galactosidase. This enzyme has two primary functions: it cleaves the disaccharide lactose into its component monosaccharides, glucose and galactose, and it also converts a small amount of lactose into allolactose, which acts as the inducer for the system.

123. (A) Allolactose
While lactose is the substrate for the lac operon, it is not the actual molecule that triggers gene expression. Instead, a small amount of lactose is converted into an isomer called allolactose by the enzyme beta-galactosidase. Allolactose serves as the natural inducer by binding directly to the lac repressor, preventing it from associating with the operator sequence.

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124. (C) cAMP levels are low.
The lac operon is also regulated by the availability of glucose, a process called catabolite repression. This is mediated by the intracellular levels of cyclic AMP. When glucose is abundant, the activity of adenylate cyclase is inhibited, leading to low levels of cyclic AMP. Without enough cAMP to bind the catabolite activator protein, the operon cannot be expressed fully.

125. (D) Negative repressible control
The trp operon regulates the synthesis of the amino acid tryptophan. It is a negative system because it is controlled by a repressor protein. Unlike the lac operon, it is repressible because the repressor is normally inactive. Only when tryptophan levels are high does the amino acid bind the repressor, activating it to block further transcription of structural genes.

126. (C) Promoting premature termination of transcription
Attenuation is an additional layer of control in several bacterial biosynthetic operons, including the trp operon. It functions by sensing the rate of translation of a leader peptide. If tryptophan is abundant, the ribosome moves quickly, which causes the nascent messenger RNA to form a specific terminator hairpin. This structure triggers the RNA polymerase to drop off the DNA.

127. (B) 3-4 loop
The mechanism of attenuation in the trp operon depends on the formation of alternative secondary structures in the leader mRNA. There are four regions that can form base-paired stems.

When tryptophan levels are high, the ribosome covers region two, allowing regions three and four to pair. This three-four stem-loop acts as an intrinsic transcription terminator, causing premature cessation.

128. (D) Constitutive expression regardless of lactose presence
In the lac operon system, the lacI gene produces the repressor protein that normally keeps the operon turned off in the absence of lactose. If a mutation occurs that prevents the synthesis of a functional repressor, there is no protein to bind to the operator. Consequently, the RNA polymerase can bind to the promoter and transcribe the structural genes continuously.

129. (A) CAP (Catabolite Activator Protein)
Bacteria prefer to use glucose as their primary energy source. To ensure this preference, they use a global regulator called the catabolite activator protein. When glucose is scarce and cyclic AMP levels rise, the cAMP-CAP complex binds to specific sites near the promoters of various operons for alternative sugars. This binding recruits RNA polymerase for high-level gene expression.

130. (D) A is false but R is true.
The first statement is false because the lac operon is not expressed at maximal levels when both sugars are present. Even if lactose removes the repressor, the presence of glucose keeps cyclic AMP levels low. Without the cAMP-CAP complex, transcription remains at a basal, low level. The second statement is a correct description of how lactose induces the operon.

131. (A) Jacob and Monod
The concept of the operon as a coordinated unit of gene expression was a revolutionary discovery in molecular biology. It was first proposed in 1961 by François Jacob and Jacques Monod based on their elegant genetic studies of lactose metabolism in Escherichia coli. Their work established the fundamental principles of how genes are turned on and off responding to environment.

132. (D) It acetylates non-metabolizable beta-galactosides for detoxification
The lac operon contains three structural genes: lacZ, lacY, and lacA. While the roles of beta-galactosidase and permease are well-known for lactose utilization, the function of the lacA product, thiogalactoside transacetylase, is less central. It catalyzes the transfer of an acetyl group from acetyl-CoA to certain non-metabolizable beta-galactosides. This modification is thought to help detoxify these compounds.

133. (B) DNA sequence
Epigenetics refers to the study of heritable changes in gene function that occur without any alteration to the underlying DNA sequence. These changes are instead mediated by chemical modifications to the DNA itself, such as methylation, or to the histone proteins that package the DNA. These modifications influence how the genetic information is read and can be inherited.

134. (C) CpG
In the genomes of mammals and many other eukaryotes, DNA methylation is a major epigenetic mark. This modification involves the addition of a methyl group to the five-position of the cytosine ring. This almost exclusively occurs at cytosines that are immediately followed by a guanine residue in the five-prime to three-prime direction, a sequence motif known as a CpG dinucleotide.

135. (D) Transcriptional silencing
The distribution of DNA methylation across the genome is not random. Clusters of CpG dinucleotides, called CpG islands, are often found in the promoter regions of genes. When these islands become hypermethylated, they generally lead to the stable silencing of the associated gene. This occurs because the methyl groups can physically block transcription factor binding or recruit silencing proteins.

136. (A) Loosening of chromatin structure and transcriptional activation
Histone acetylation is a key regulatory modification of chromatin. Histone acetyltransferases add acetyl groups to the positively charged lysine residues on histone tails. This modification neutralizes the positive charge, reducing the electrostatic attraction between the histones and the negatively charged DNA. As a result, the chromatin structure loosens, making the DNA more accessible to RNA polymerase and other transcription-related machinery.

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196. (D) Sticky or cohesive ends
Restriction enzymes can cut DNA in two different ways. Many enzymes, like EcoRI or HindIII, make staggered cuts in the sugar-phosphate backbone. This results in fragments with short, single-stranded overhangs. These are known as sticky or cohesive ends because they can easily base-pair with complementary overhangs from another DNA fragment, facilitating the process of ligation and chimeric creation.

197. (B) DNA Ligase
In recombinant DNA technology, creating a chimeric molecule requires the covalent joining of DNA fragments from different sources. DNA ligase is the enzyme used for this purpose. It catalyzes the formation of a phosphodiester bond between the three-prime hydroxyl group of one fragment and the five-prime phosphate group of another. This reaction effectively seals the backbone for cloning.

198. (C) Genus, species, and strain of the source bacterium
The naming of restriction enzymes follows a standardized system based on their origin. The first letter comes from the genus of the source bacterium, and the next two letters from the species name. Additional letters or numbers indicate the specific strain and the order in which the enzyme was discovered in that organism, such as in HindIII.

199. (D) To protect the host DNA from cleavage by its own restriction enzyme
Bacterial restriction-modification systems consist of two enzymes: a restriction endonuclease and a modification methylase. Both enzymes recognize the same DNA sequence. The methylase adds a methyl group to specific bases within the recognition site on the host's own genome. This chemical modification prevents the restriction enzyme from binding and cutting the bacterial DNA while allowing foreign degradation.

200. (A) P-3, Q-1, R-2, S-4
Molecular cloning requires several specialized enzymes. Restriction endonucleases cut DNA at specific sites. Reverse transcriptase is used to synthesize complementary DNA from an RNA template. DNA ligase covalently joins these fragments together. Finally, alkaline phosphatase is used to remove the five-prime phosphate groups from the ends of a linearized vector, which prevents the vector from re-sealing alone.

201. (B) Cleave DNA at random sites far from the recognition sequence.
Although type one restriction enzymes were the first to be discovered, they are not useful for precise DNA manipulation. While they bind to specific recognition sequences, they track along the DNA and cut at essentially random sites, often thousands of base pairs away. This unpredictable cleavage pattern makes it impossible to use them for isolating specific genes or creating constructs.

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202. (B) Add homopolymeric tails to the 3' ends of DNA fragments
Terminal deoxynucleotidyl transferase is a unique DNA polymerase that does not require a template. It is used in cloning to add a string of identical nucleotides, such as poly-A or poly-C, to the three-prime ends of DNA molecules. This technique, called homopolymeric tailing, allows for the creation of complementary cohesive ends between fragments that originally had blunt.

203. (A) Recognize the exact same DNA sequence
In molecular biology, isochizomers are pairs of restriction enzymes that are isolated from different bacterial species but recognize the exact same DNA sequence. For example, MboI and Sau3AI both recognize the sequence G-A-T-C. While they share the same recognition site, isochizomers may differ in their sensitivity to DNA methylation or the specific location where they cut strands.

204. (C) Remove 5'-phosphate groups, thereby preventing self-circularization
When preparing a vector for cloning, it is often treated with alkaline phosphatase. This enzyme removes the five-prime phosphate groups from the ends of the linearized DNA. Because DNA ligase requires a five-prime phosphate to form a bond, the vector can no longer re-circularize on its own. This forces the vector to incorporate the insert DNA for successful ligation.

205. (D) Origin of replication (ori)
A cloning vector is a DNA molecule used to carry foreign genetic material into a host cell. To be effective, the vector must be able to replicate independently within the host. This requirement is fulfilled by the presence of a specific DNA sequence called the origin of replication. This

genetic material. The mitochondrial genome typically consists of multiple copies of a small, double-stranded DNA molecule that is closed in a circular conformation. This genome encodes essential components of the oxidative phosphorylation system, as well as the transfer RNAs and ribosomal RNAs required for their own internal synthesis.

147. (A) Maternal inheritance
In the majority of flowering plants, or angiosperms, the transmission of organellar genomes does not follow Mendelian rules. Instead, chloroplasts are typically inherited through the female parent. This occurs because the egg cell provides nearly all of the cytoplasm to the zygote, while the pollen tube contributes only the male nucleus. Consequently, traits encoded by the chloroplast are passed maternally.

148. (D) Mitochondrial genome
Cytoplasmic male sterility is a condition in plants where they are unable to produce functional pollen, but their female fertility remains unaffected. This trait is caused by specific mutations or rearrangements within the mitochondrial genome. Because mitochondria are inherited maternally, this sterility can be passed to all offspring. CMS is a valuable tool for simplified production of hybrids.

149. (B) Restorer of fertility (Rf) genes
Although cytoplasmic male sterility is caused by mitochondrial genes, its expression can be suppressed by the nuclear genome. Many plant species possess nuclear genes known as restorer of fertility genes. When these Rf genes are present, they interfere with the mitochondrial CMS factors, thereby restoring the ability of the plant to produce functional and healthy pollen in the hybrid offspring.

150. (A) I and II
The chloroplast genome is a circular DNA molecule that displays several interesting features. It typically contains a large inverted repeat region. Furthermore, it encodes many of the proteins involved in photosynthesis, including the large subunit of the key enzyme RuBisCO. However, statement three is incorrect because chloroplasts possess their own internal ribosomes (70S) for protein synthesis.

151. (D) Heteroplasmy
Unlike the nuclear genome, which is present in two copies per cell, organellar genomes exist in hundreds or thousands of copies. Heteroplasmy is the condition where a single cell or individual contains a mixture of different organellar DNA genotypes. This often occurs when a mutation arises in some, but not all, copies of the mitochondrial or chloroplast DNA.

152. (A) Degradation of paternal mitochondria after fertilization
While sperm cells do contain mitochondria to power their motility, these paternal organelles rarely contribute to the next generation in mammals. Upon fertilization, the paternal mitochondria that enter the egg are specifically identified and destroyed by the cell's degradation machinery, such as the ubiquitin-proteasome system. This active elimination ensures that the offspring inherit mitochondrial DNA exclusively from the mother.

153. (B) Much larger and undergo frequent recombination
Mitochondrial genomes vary tremendously in size and structure across different kingdoms. In animals, the mitochondrial DNA is very small and compact. In contrast, plant mitochondrial genomes are significantly larger and more complex. They contain large amounts of non-coding DNA and are prone to frequent intra-molecular recombination, which results in a collection of sub-genomic circular and linear DNA molecules.

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154. (B) Prokaryotic cells (70S)
Reflecting their evolutionary origin from endosymbiotic bacteria, the ribosomes found within chloroplasts are fundamentally different from the eighty-S ribosomes found in the eukaryotic cytosol. Chloroplast ribosomes have a sedimentation coefficient of seventy-S and are composed of thirty-S and fifty-S subunits. They are also sensitive to many of the same antibiotics that target bacterial protein synthesis machinery.

155. (A) Ribulose-1,5-bisphosphate carboxylase/ oxygenase (RuBisCO)
RuBisCO is the most abundant enzyme on Earth and is central to the process of carbon fixation. It is a multi-subunit complex composed of eight large subunits and eight small subunits. In plants, the large subunits are encoded by the

kilobases, necessitating the use of specialized vectors.

216. (A) It allows the recovery of single-stranded cloned DNA.
The M13 bacteriophage has a unique life cycle where it packages its genome as single-stranded DNA and releases the new virions without killing the host bacterium. This feature was historically very useful for Sanger sequencing, which required a single-stranded template. By cloning a gene into M13, researchers could easily obtain high-quality single-stranded DNA from the phage particles.

217. (B) The complete DNA content of an organism
A genomic library is a collection of cloned DNA fragments that collectively represent the entire genome of a particular organism. To construct such a library, the total genomic DNA is purified, fragmented into manageable sizes, and then inserted into a population of cloning vectors. Ideally, this library contains every sequence present in the organism, including exons and introns.

218. (A) Mature mRNA
A complementary DNA library is a collection of DNA copies synthesized from the total messenger RNA of a specific cell or tissue. Because it is derived from mature mRNA, the library only contains the coding sequences of the genes that were being actively expressed at the time of collection. This makes it a valuable tool for studying specialized transcriptomes.

219. (A) Oligo(dT) primers
To synthesize cDNA, reverse transcriptase requires a primer to begin elongation. Most eukaryotic messenger RNAs are characterized by a long poly-adenosine tail at their three-prime end. Researchers exploit this feature by using a synthetic oligonucleotide consisting of a string of thymine residues. This oligo-dT primer base-pairs with the poly-A tail, providing the starting point for cDNA synthesis.

220. (C) A cDNA library lacks introns and regulatory regions.
There is a fundamental structural difference between genomic and cDNA libraries. Genomic DNA contains all elements of the chromosome, including non-coding introns and distant regulatory regions like promoters. In contrast, cDNA is synthesized from processed messenger RNA, where introns have already been removed by splicing. Therefore, cDNA clones represent ready-to-translate versions of genes, lacking complex genomic architecture.

221. (D) To provide restriction sites for blunt-ended DNA fragments
Ligation is most efficient when the DNA fragments have matching cohesive ends. When researchers have blunt-ended DNA, they can use linkers or adaptors to solve this problem. These are short, synthetic double-stranded DNA molecules that contain specific restriction sites. By ligating these molecules onto the ends of the blunt fragments, researchers can then generate the desired sticky ends.

222. (C) Probe
Identifying a specific clone within a library requires a way to detect its unique sequence. A probe is a fragment of DNA or RNA with a known sequence that is complementary to the target gene. The probe is labeled with a radioactive isotope or a fluorescent tag. Under correct conditions, the probe will hybridize only to its matching sequence.

223. (B) BAC or YAC
The choice of vector for library construction depends on the complexity of the genome. For large and complex eukaryotic genomes, standard plasmids or phages are inefficient because they can only carry small fragments. To minimize the number of clones needed to cover the entire genome, researchers use high-capacity vectors like bacterial or yeast artificial chromosomes for better coverage.

224. (D) RNase H
After the first strand of cDNA is synthesized by reverse transcriptase, the template RNA must be removed to allow for second-strand synthesis. The enzyme RNase H is specifically used for this purpose because it degrades only the RNA portion of an RNA-DNA hybrid. This leaves the first cDNA strand intact and creates small RNA primers for the polymerase.

225. (A) Functional promoter and ribosome binding sites for the host
Expression libraries are designed not just to store DNA, but to allow the cloned genes to be transcribed and translated into proteins within

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166. (C) CI and Cro
The life cycle decision of bacteriophage lambda is a paradigm of genetic switching. It involves a sophisticated genetic circuit where two repressor proteins, CI and Cro, compete for the same operator sites. If CI protein levels are high, it stabilizes the lysogenic state. If Cro protein accumulates first, it inhibits the production of CI and triggers the lytic genes.

167. (D) Cellular DNA damage and the SOS response
A prophage can be induced to leave the lysogenic state and enter the lytic cycle if the host cell's survival is threatened. A major trigger for this induction is DNA damage, which activates the bacterial SOS response. During this response, the RecA protein becomes activated and promotes the self-cleavage of the lambda repressor, allowing lytic gene expression.

168. (A) Insertion of viral DNA into the host chromosome
After reverse transcriptase has produced a double-stranded DNA copy of the retroviral genome, the DNA must be incorporated into the host's genetic material. This task is performed by the viral enzyme integrase. The enzyme catalyzes the precise insertion of the viral cDNA at semi-random locations in the host's chromosomes, creating a provirus that can be stably inherited.

169. (B) Pyrimidine dimers
Ultraviolet radiation, particularly at wavelengths around two hundred and sixty nanometers, is strongly absorbed by the nitrogenous bases of DNA. This absorption of energy can cause the formation of covalent bonds between adjacent pyrimidine bases, most commonly two thymines. These pyrimidine dimers distort the double helix and block both DNA replication and transcription, potentially leading to mutations.

170. (A) I, II and III
Chemical mutagens induce genetic changes through various mechanisms. Nitrous acid deaminates bases, while ethidium bromide is a flat molecule that intercalates between base pairs, potentially causing frameshifts. Five-bromouracil is a base analog that mimics thymine but can pair with guanine, leading to transitions. Alkylating agents can cause transitions or transversions, while base analogs typically cause specific transitions.

171. (A) DNA glycosylases
Base excision repair is the primary pathway for fixing small, non-bulky DNA lesions such as uracil or oxidized bases. The process is initiated by a family of enzymes called DNA glycosylases. Each glycosylase is specific for a particular type of damaged base. The enzyme works by flipping the base out of the helix and cleaving the N-glycosidic bond.

172. (C) Bulky, helix-distorting lesions
Nucleotide excision repair is a versatile and essential DNA repair mechanism. Unlike other pathways that recognize specific base changes, this system identifies significant distortions in the shape of the double helix. These distortions are often caused by bulky adducts or ultraviolet-induced pyrimidine dimers. The machinery works by cutting the damaged strand on both sides of the structural lesion.

173. (D) The absence of methylation on the newly synthesized strand
To correct errors made during replication, the mismatch repair system must distinguish between the correct template strand and the erroneous new strand. In Escherichia coli, this is achieved through DNA methylation at G-A-T-C sequences. Immediately after replication, the template strand is methylated while the new strand is not. This hemimethylated state allows the repair proteins to target the new.

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174. (C) Nonsense mutation
A nonsense mutation is a type of point mutation where a single nucleotide change converts a codon that specifies an amino acid into one of the three stop codons. This results in the premature termination of the polypeptide chain during translation. Consequently, the produced protein is truncated and usually non-functional, which can have severe phenotypic consequences for the cell.

175. (B) Uracil
DNA bases are susceptible to spontaneous chemical modifications. Deamination is a common reaction where an amino group is lost from a base. When cytosine undergoes deamination, it is converted into uracil. Because uracil is not a standard base in DNA, it is usually recognized and removed by the base excision repair system. If unrepaired, it pairs with adenine.

chloroplast genome and synthesized internally, while the small subunits are encoded by the nuclear genome and imported into chloroplasts.

156. (C) Extranuclear
In plant breeding, backcrossing is used to transfer a specific trait into a desired genetic background. If a trait like cytoplasmic male sterility continues to be expressed even after many generations of crossing with a recurrent male parent, it indicates that the trait is not controlled by nuclear genes. Instead, the trait is inherited through the cytoplasm, confirming its extranuclear nature.

157. (D) Temperate phages
Bacteriophages exhibit two main types of life cycles. Virulent phages always multiply rapidly and lyse their host cell. In contrast, temperate phages have the ability to choose an alternative pathway. They can integrate their DNA into the host's chromosome, where it remains dormant for many generations. This lysogenic state allows the virus to replicate along with the bacterium.

158. (C) Prophage
When a temperate bacteriophage enters the lysogenic cycle, its DNA becomes a stable part of the bacterial genome. In this integrated and largely repressed state, the viral genome is called a prophage. The prophage is replicated every time the host cell divides, and it can remain in this state indefinitely until environmental triggers induce it to exit dormancy.

159. (B) CI repressor (Lambda repressor)
The maintenance of lysogeny in bacteriophage lambda is dependent on a single master regulator. The CI protein, also known as the lambda repressor, binds to specific operator sites on the viral DNA. This binding blocks the transcription of the genes required for the lytic cycle while simultaneously stimulating the production of more CI protein, ensuring a stable dormancy.

160. (B) II and III
The lytic cycle is the productive and destructive phase of a viral infection. It is characterized by the rapid hijacking of the host's cellular machinery to replicate the viral genome and synthesize capsid proteins. This leads to the assembly of numerous new virions within the cell. The cycle culminates in the lysis of the host cell for release.

161. (A) Reverse transcriptase
Retroviruses are a unique class of viruses that store their genetic information as single-stranded RNA. To replicate, they must convert this RNA into double-stranded DNA that can be integrated into the host genome. This essential step is performed by the viral enzyme reverse transcriptase. This discovery challenged the central dogma by showing that information can flow from RNA back to DNA.

162. (C) Host RNA polymerase II
Once a retrovirus has integrated its DNA into the host's chromosome, it is known as a provirus. In this state, it behaves like a normal cellular gene. To produce new viral particles, the provirus must be transcribed into RNA. The virus uses the host cell's own RNA polymerase two enzyme to synthesize these transcripts, which serve as mRNA.

163. (A) Insect vectors (e.g., aphids)
Unlike animal viruses, plant viruses cannot easily penetrate the thick, rigid cell walls of their hosts. To overcome this barrier, they have evolved to rely on external agents for transmission. Most plant viruses are spread by sap-sucking insects, particularly aphids, whiteflies, and leafhoppers. These vectors pick up the virus from an infected plant and inject healthy tissue.

164. (D) Positive-sense single-stranded RNA
The majority of plant viruses characterized to date possess a genome consisting of single-stranded RNA. Specifically, most are positive-sense, meaning the viral RNA can be directly translated by the host's ribosomes into proteins immediately upon entry into the cell. Tobacco Mosaic Virus is the classic example of this group, featuring a simple rod-shaped structure and RNA molecule.

165. (B) Via plasmodesmata
After successfully infecting a single plant cell, a virus must spread to neighboring cells to colonize the entire host. Plant cells are connected to each other by narrow cytoplasmic channels called plasmodesmata. Viruses have evolved specialized movement proteins that can modify these channels, allowing the viral genome or the entire nucleoprotein complex to pass through the cell wall.

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186. (B) G1/S transition
The p53 protein is a transcription factor that is activated by DNA damage. One of its primary roles is to induce the expression of the CDK inhibitor p21. This inhibitor blocks the activity of the cyclin-CDK complexes that are necessary for the cell to move past the G1 checkpoint and enter S phase, allowing repair time.

187. (A) Small GTPase
The Ras gene family encodes a group of small GTPase proteins that function as molecular switches in signal transduction pathways. They cycle between an active GTP-bound state and an inactive GDP-bound state. Oncogenic mutations in Ras typically impair its ability to hydrolyze GTP, leaving the protein permanently in the on position. This leads to continuous downstream signaling for division.

188. (C) Bcl-2
Apoptosis is a highly regulated process of programmed cell death, and its evasion is a hallmark of cancer. The Bcl-2 family of proteins contains both pro-apoptotic and anti-apoptotic members that control the release of cytochrome c from mitochondria. Bcl-2 itself is a prominent anti-apoptotic protein that prevents cell death. Its over-expression in many cancers allows malignant survival.

189. (D) BCR-ABL
Chromosomal translocations can create novel fusion genes with oncogenic properties. In chronic myelogenous leukemia, a translocation between chromosomes nine and twenty-two swaps the BCR and ABL genes. The resulting Philadelphia chromosome contains the BCR-ABL fusion gene, which encodes a constitutively active tyrosine kinase. This mutant protein drives the overproduction of white blood cells and is a therapy target.

190. (A) Both A and R are true and R is the correct explanation of A.
Normal somatic cells have a limited lifespan because their telomeres shorten with every division. To achieve immortality, cancer cells must find a way to maintain their chromosome ends. In the majority of cancers, this is achieved by the upregulation of telomerase. This enzyme prevents telomere depletion, allowing the cells to bypass replicative senescence and continue dividing indefinitely.

191. (B) Tumor suppressor genes
Loss of heterozygosity is a common genetic event in the progression of many tumors. It refers to the loss of the remaining functional allele in a cell that was already heterozygous for a tumor suppressor gene mutation. According to the two-hit hypothesis, this loss removes the last genetic brake on cell growth, leading to a complete loss of function.

192. (D) Cyclin-dependent kinases (CDKs)
The cell cycle is controlled by a core machinery of protein kinases. These enzymes are only active when they are bound to regulatory subunits called cyclins. These cyclin-dependent kinase complexes act as the master switches that trigger the various events of the cell cycle, such as DNA replication and mitosis. Their activity is precisely regulated by various cellular signals.

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193. (A) Provide defense against viral (bacteriophage) infection
Restriction endonucleases are powerful tools in biotechnology, but their original biological function is to protect bacteria from foreign DNA. They are part of a restriction-modification system. These enzymes recognize and cut specific DNA sequences common in viral genomes. By degrading the DNA of invading bacteriophages, bacteria can prevent infection and ensure their own survival in competitive environments.

194. (C) Cleave DNA at precise locations within or adjacent to their recognition sites.
While there are several types of restriction enzymes, type two endonucleases are the workhorses of molecular cloning. Their primary advantage is that they recognize specific, usually palindromic, sequences and cut the DNA at predictable and precise locations within or very close to those sites. This reproducibility allows scientists to cut and paste DNA fragments with high accuracy for research.

195. (A) Palindromic
Most type two restriction endonucleases recognize specific DNA sequences that exhibit a particular type of symmetry. These sequences are palindromic, meaning the five-prime to three-prime sequence is the same on both strands of the double helix. For example, the recognition site for EcoRI is G-A-A-T-T-C. This symmetry allows the enzyme, often functioning as a homodimer, to bind.

137. (B) Histone deacetylases (HDACs)
The level of histone acetylation in a cell is determined by the balance between the activities of two classes of enzymes. While HATs add acetyl groups, histone deacetylases are responsible for removing them. The activity of HDACs restores the positive charge to the lysine residues, promoting a more condensed and transcriptionally inactive chromatin state. HDACs are associated with gene repression.

138. (B) Genomic imprinting
Genomic imprinting is a unique epigenetic phenomenon in which only one allele of a gene is expressed, depending on which parent it was inherited from. This is achieved through the establishment of sex-specific DNA methylation patterns during gametogenesis. For an imprinted gene, either the maternal or paternal copy is consistently silenced across generations, which is essential for normal development.

139. (A) Sliding or ejecting nucleosomes to expose DNA regulatory elements
Beyond chemical modifications, chromatin structure can be physically altered by specialized enzymes. ATP-dependent chromatin remodeling complexes use the energy of ATP hydrolysis to change the position or composition of nucleosomes. By sliding nucleosomes along the DNA or ejecting them entirely, these complexes can expose promoters and enhancers that were previously hidden, thereby facilitating the initiation of the transcription process.

140. (A) P-4, Q-3, R-2, S-1
Epigenetic marks are strongly correlated with the transcriptional state of the genome. DNA methylation at promoters and H3K9 trimethylation are generally associated with gene silencing and heterochromatin formation. Conversely, histone acetylation is a broad mark for activation, and H3K4 trimethylation is a specific hallmark of actively transcribing promoters. These marks define the functional landscape of chromosomes.

141. (D) X-chromosome inactivation
Female mammals possess two X chromosomes, while males have only one. To prevent females from producing double the amount of X-linked gene products, they utilize a dosage compensation mechanism. Early in embryonic development, one of the two X chromosomes in each female cell is randomly selected and undergoes massive epigenetic silencing. This inactivated chromosome becomes a highly condensed Barr body.

142. (C) XIST
The process of X-chromosome inactivation is controlled by a specific region called the X-inactivation center. This region encodes a long non-coding RNA molecule named XIST. During the inactivation process, the XIST RNA is transcribed from the chromosome that will be silenced. The RNA molecules then spread and coat the entire chromosome in cis, triggering the recruitment of silencing factors.

143. (B) H3K4me3
Different patterns of histone methylation serve as specific signals for the cell's transcriptional machinery. While some methylation marks, like H3K9me3 or H3K27me3, are associated with gene repression, others are indicators of activity. Specifically, the trimethylation of lysine four on histone H3 is found almost exclusively at the promoter regions of genes that are being actively transcribed.

144. (D) Hemimethylated DNA during replication
For epigenetic information to be heritable, it must be accurately copied during cell division. Maintenance DNA methyltransferases, such as DNMT1, perform this function. Following DNA replication, the parental strand remains methylated while the new daughter strand is unmethylated, creating hemimethylated DNA. DNMT1 specifically recognizes these sites and adds a methyl group to the daughter strand, ensuring pattern preservation.

145. (A) Bacteria
The endosymbiotic theory provides the most widely accepted explanation for the origin of eukaryotic organelles. It proposes that mitochondria and chloroplasts were once free-living prokaryotic organisms that were engulfed by a primitive ancestral eukaryotic cell. Over time, they established a symbiotic relationship, eventually losing many of their genes to the host nucleus and becoming specialized energy-converting organelles.

146. (C) Circular, double-stranded DNA
Consistent with their prokaryotic origins, animal mitochondria contain their own independent

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site is recognized by the host cell's replication machinery during growth.

206. (C) Multiple cloning site (MCS)
Modern cloning vectors are engineered to be highly functional. A key feature is the multiple cloning site, also known as a polylinker. This is a short, synthetic DNA sequence that contains unique recognition sites for several different restriction enzymes. By providing many options for insertion in one location, the MCS makes it easy for researchers to clone fragments.

207. (B) Bacterial Artificial Chromosome (BAC)
Bacterial artificial chromosomes are specialized vectors designed for cloning large segments of DNA. They are based on the F-factor plasmid of Escherichia coli, which is naturally maintained at a low copy number. This stability allows BACs to reliably carry and replicate inserts ranging from one hundred to three hundred kilobases, making them essential for large-scale genome mapping.

208. (D) F-factor origin (oriS)
Yeast artificial chromosomes are designed to behave like natural chromosomes within a yeast cell. They require three essential structural elements: an autonomous replicating sequence for initiation, a centromere for proper segregation during division, and telomeres to protect the linear ends. The F-factor origin is a component of bacterial vectors like BACs and is not used in yeast.

209. (A) Bacteriophage lambda (cos sites)
Cosmids are sophisticated hybrid vectors that combine the useful features of both plasmids and bacteriophages. They are essentially plasmids that have had the lambda phage cohesive end sites, or cos sites, inserted. This allows the recombinant DNA to be packaged into lambda phage heads in vitro, which is a highly efficient way to introduce large DNA fragments.

210. (C) Ti plasmid of Agrobacterium tumefaciens
Agrobacterium tumefaciens is a soil bacterium that has been nicknamed nature's smallest genetic engineer. It contains a large tumor-inducing plasmid. In nature, the bacterium uses this plasmid to transfer a segment of its own DNA into a plant's genome. Researchers have adapted this system into a powerful vector for creating transgenic crops by replacing genes with desired traits.

211. (A) T-DNA
The Ti plasmid contains a specific region known as the transfer DNA. This segment is flanked by twenty-five base pair border sequences that are recognized by the bacterium's virulence machinery. During the infection process, the T-DNA is excised, transported into the plant cell, and stably integrated into the nuclear genome. This unique ability makes T-DNA the ideal vehicle.

212. (D) Selectable markers
In molecular cloning, it is essential to distinguish between cells that have taken up the vector and those that have not. Selectable markers are genes that provide a measurable advantage under certain conditions. In the plasmid pBR322, the genes for ampicillin and tetracycline resistance allow only transformed bacteria to grow on media containing these antibiotics, effectively filtering cells.

213. (B) lacZ
Blue-white screening is a popular method for identifying recombinant clones. It uses a modified version of the lacZ gene which encodes the alpha-peptide of beta-galactosidase. When foreign DNA is inserted into the multiple cloning site within this gene, the gene's function is disrupted. This insertional inactivation prevents the production of a functional enzyme, enabling rapid colony selection.

214. (C) White colonies
In a blue-white screening assay, the chromogenic substrate X-gal is added to the growth medium. Bacteria with an intact lacZ gene produce beta-galactosidase, which cleaves X-gal and turns the colony blue. If a DNA fragment has been successfully inserted into the vector, the lacZ gene is inactivated. These recombinant bacteria cannot process X-gal and therefore grow as white.

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215. (D) Transformation efficiency drops sharply with large plasmids
While standard plasmids are easy to work with, they have a limited capacity for large DNA inserts. As the size of the plasmid increases, its ability to be taken up by competent bacteria during transformation decreases dramatically. This makes it difficult to recover recombinant clones with inserts larger than ten to fifteen

176. (D) Thymine
Many cytosine residues in the genome are methylated as part of epigenetic regulation. When 5-methylcytosine undergoes deamination, the resulting base is thymine. Unlike uracil, thymine is a normal component of DNA, making this specific lesion much harder for the cellular repair machinery to detect. This often leads to C-to-T transition mutations, which are a major source of variation.

177. (A) Photoreactivation
Photoreactivation is a direct DNA repair mechanism found in many organisms, though not in placental mammals. It utilizes an enzyme called DNA photolyase. This enzyme binds to ultraviolet-induced pyrimidine dimers and uses energy from visible light to break the abnormal covalent bonds between the bases. This restores the original structure of the DNA without the need for strand excision.

178. (C) Purine to Purine or Pyrimidine to Pyrimidine
Base substitutions are classified into two types based on the chemical nature of the change. A transition is a mutation where a purine is replaced by another purine, or a pyrimidine is replaced by another pyrimidine. These changes are more common than transversions, where a purine is swapped for a pyrimidine or vice versa, because they are structurally less disruptive.

179. (A) SOS response
When a bacterial cell experiences overwhelming DNA damage that blocks replication, it activates a global stress response called the SOS response. This pathway induces the expression of specialized error-prone DNA polymerases. These enzymes can synthesize DNA across from lesions that would stop the normal replicative polymerase. While this allows survival and replication completion, it often introduces many new mutations.

180. (A) III, II, IV, I
The base excision repair pathway follows a logical sequence of enzymatic steps. First, a DNA glycosylase removes the damaged base. Next, an AP endonuclease cleaves the sugar-phosphate backbone at the resulting empty site. DNA polymerase then uses the intact strand as a template to fill in the correct nucleotide. Finally, DNA ligase seals the nick to restore DNA.

181. (B) Proto-oncogenes
Proto-oncogenes are a diverse group of normal cellular genes that play essential roles in regulating cell growth, differentiation, and survival. They often encode proteins such as growth factors, receptors, and signaling kinases. When these genes undergo mutations that increase their activity or expression, they are transformed into oncogenes, which drive the uncontrolled proliferation characteristic of cancer cells.

182. (C) One
Mutations that transform proto-oncogenes into oncogenes are typically gain-of-function mutations. Because these mutations result in a protein that is overactive or constitutively expressed, they act in a dominant fashion at the cellular level. This means that a mutation in only one of the two alleles is sufficient to promote abnormal cell growth and contribute to cancer development.

183. (D) p53
Tumor suppressor genes are the brakes of the cell cycle, acting to prevent uncontrolled division. The p53 gene is the most well-known example and is often called the guardian of the genome. It monitors DNA integrity and can trigger cell cycle arrest or apoptosis in response to damage. In contrast, Ras, Myc, and Src are proto-oncogenes.

184. (A) Tumor suppressor genes
The two-hit hypothesis explains the genetic basis of many cancers, particularly hereditary ones like retinoblastoma. It states that for a tumor suppressor gene, which normally functions to inhibit cell growth, both alleles must be inactivated for cancer to develop. In hereditary cases, the first hit is inherited, while in sporadic cases, both mutations must occur independently in the same cell.

185. (B) E2F
The retinoblastoma protein is a critical negative regulator of the cell cycle. In its unphosphorylated state, Rb binds to the E2F transcription factor, preventing it from activating the genes required for the transition from G1 to S phase. When the cell receives growth signals, Rb is phosphorylated by cyclin-CDK complexes, causing it to release E2F and progress.

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the host cell. To achieve this, the vectors used in an expression library are equipped with powerful regulatory sequences, including a promoter and a ribosome binding site, positioned correctly relative to the insert's location.

226. (C) Expression library
Immunological screening involves using antibodies to detect the specific protein product of a cloned gene. For this method to work, the host cell must be actively producing the protein from the inserted DNA. Therefore, this type of screening is only possible with an expression library, where the vector contains the necessary signals for transcription and translation of cDNA.

227. (A) Partial digestion with restriction enzymes
When constructing a genomic library, it is important to create a set of overlapping DNA fragments. If the DNA is digested to completion, every copy will be cut at the same sites, and no overlap will exist. By using a limited amount of enzyme or a short incubation time, researchers achieve partial digestion. This generates random overlapping fragments.

228. (D) Have pre-formed cohesive ends, preventing their self-ligation
While both linkers and adaptors add restriction sites to blunt ends, adaptors offer a significant practical advantage. Linkers are blunt-ended and can ligate to each other in long chains, requiring additional digestion steps. Adaptors are synthesized with one blunt end and one pre-formed cohesive end. Because the cohesive ends are not complementary to each other, adaptors cannot self-ligate.

229. (B) Isolate overlapping genomic clones to traverse large chromosomal regions
Chromosome walking is a directional method used to move from a known genetic marker toward a target gene. It involves using the end of one cloned DNA fragment as a probe to identify an overlapping clone in a genomic library. By repeating this process, researchers can walk along the chromosome step-by-step, eventually reaching the target gene for isolation.

230. (C) Dispersed highly repetitive DNA sequences
A major challenge for chromosome walking in eukaryotic organisms is the abundance of repetitive DNA. If a walking probe contains a sequence that is repeated hundreds of times throughout the genome, it will hybridize to many different clones in the library. This makes it impossible to determine which clone is truly adjacent to the starting point, effectively halting progress.

231. (D) Bypass unclonable or repetitive regions by connecting distant loci
Chromosome jumping was developed to overcome the limitations of chromosome walking. Instead of moving step-by-step along the DNA, jumping allows researchers to cover large distances in a single step. This is achieved by circularizing large DNA fragments and then cloning only the junction where the distant ends meet. This technique is particularly useful for skipping large repetitive regions.

232. (A) Inducing a mutant phenotype through the insertion of a known mobile genetic element
Transposon tagging is a powerful forward genetics technique for isolating genes. It works by using transposable elements as molecular tags. When a transposon jumps into a gene, it disrupts its function, creating a mutant phenotype. Because the sequence of the transposon is known, researchers can then use it as a probe to easily clone and identify genes.

233. (B) Ac/Ds elements
The first transposable elements were discovered in maize by Barbara McClintock, a finding that eventually earned her a Nobel Prize. She identified the Activator (Ac) and Dissociation (Ds) system. Ac is an autonomous element that can move on its own, while Ds is a non-autonomous element that requires Ac to jump. This system remains a classic tool.

234. (C) Genetic map position relative to closely linked markers
Map-based cloning is a strategy used to isolate a gene based on its location in the genome, rather than its function. The first step is to perform high-resolution genetic mapping to find molecular markers that are very close to the gene. These markers then serve as starting points for physical mapping and chromosome walking to pinpoint the gene.

235. (A) RAPD
Random Amplified Polymorphic DNA is a molecular marker technique that does not

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structural or biological complexity. For example, some simple single-celled protozoa and certain plants have genomes that are many times larger than the human genome. This paradox is explained by the varying amounts of non-coding, repetitive DNA.

255. (B) Retrotransposons
A large portion of the eukaryotic genome consists of transposable elements that replicate via an RNA intermediate. These are known as retrotransposons. Long interspersed nuclear elements are autonomous and encode the machinery for their own movement. Short interspersed nuclear elements are non-autonomous and rely on the machinery from LINEs. Together, these elements have played a major role in genome evolution.

256. (D) Alu element
The most abundant transposable element in the human genome is the Alu element. It is a member of the SINE family and is approximately three hundred base pairs long. There are over one million copies of Alu elements scattered throughout our DNA. While they are non-coding, their insertion and subsequent recombination have had a significant impact on human genetic variation.

257. (A) Recombination frequencies during meiosis
Genetic mapping, also known as linkage mapping, is based on the principle that genes located close together on a chromosome are likely to be inherited together. By measuring the frequency of recombination events between different loci during meiosis, researchers can estimate the relative distances between them. These distances are measured in centiMorgans, where one cM equals one percent recombination frequency.

258. (C) Base pairs (bp, kb, Mb)
While genetic maps are based on recombination, physical maps are based on the actual physical distance between landmarks on the DNA. These distances are measured in absolute units of base pairs, kilobases, or megabases. Physical maps are constructed using techniques such as restriction mapping, STS mapping, and ultimately, full genome sequencing, providing a direct representation of chromosome structure.

259. (A) Genetic distances vary depending on recombination hotspots, whereas physical distances are absolute.
Although genetic and physical maps generally show the same order of genes, the distances between them can differ significantly. This is because recombination does not occur uniformly across the chromosome. Regions called recombination hotspots show high frequencies of crossing over, while other regions are suppressed. Therefore, a genetic map may exaggerate or compress the actual physical distance between loci.

260. (A) P-3, Q-2, R-4, S-1
Genomes are composed of various functional and structural elements. Microsatellites are short tandem repeats used as genetic markers. LINEs are autonomous retrotransposons that contribute to genome size. The centromere is the essential region for spindle attachment during division. Finally, pseudogenes are non-functional copies of genes that have accumulated mutations, serving as molecular fossils within the genetic code.

NODIA

261. (B) Satellite DNA
Satellite DNA consists of very large arrays of tandemly repeating, non-coding DNA sequences. These sequences are typically found in the heterochromatic regions of chromosomes, such as the centromeres and telomeres. The name satellite comes from the fact that these regions often have a different base composition than the rest of the genome, causing them to form separate bands.

262. (C) Functional transposase enzyme
Transposable elements are classified as either autonomous or non-autonomous. Autonomous elements, like Ac in maize, encode their own transposase enzyme, which is required to recognize the ends of the element and catalyze its movement. Non-autonomous elements, like Ds, have lost the gene for transposase but can still jump if an autonomous element in the same cell provides enzyme.

263. (D) Conservation of gene order and blocks of genes on chromosomes of different species
Synteny is a fundamental concept in comparative genomics. It refers to the observation that related species often share large blocks of genes in the same relative order on their chromosomes. Studying synteny allows researchers to identify

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camera, the fluorescent tag and the terminator are chemically removed, allowing the next nucleotide to be added sequentially.

245. (B) Ion Torrent
Unlike technologies that rely on light or fluorescence, Ion Torrent sequencing uses a semiconductor chip to detect chemical changes. When a nucleotide is incorporated into a DNA strand, a hydrogen ion is naturally released as a byproduct. This causes a tiny, measurable change in the pH of the surrounding solution. By monitoring these pH changes, the system determines the sequence.

246. (C) Peptide chains (Proteins)
Edman degradation is a classical method for determining the primary sequence of proteins. It works by sequentially removing and identifying one amino acid at a time from the amino terminus of a peptide chain. While it was once the gold standard for protein sequencing, it is limited by its speed and the requirement for a relatively large amount of sample.

247. (D) Phenyl isothiocyanate (PITC)
The chemistry of Edman degradation depends on a specific reagent called phenyl isothiocyanate. In a high-pH environment, PITC reacts with the free amino group of the N-terminal amino acid. Under subsequent acidic conditions, the labeled terminal amino acid is selectively cleaved as a thiazolinone derivative, which is then identified. This cyclic process is repeated to sequence entire peptides.

248. (A) Rapid analysis of very low abundance complex peptide mixtures
Mass spectrometry has revolutionized the field of proteomics. Unlike Edman degradation, which is slow and requires pure samples, mass spectrometry can identify thousands of different proteins from a complex mixture in a single experiment. Its high sensitivity allows for the detection of low-abundance proteins and their modifications, making it an essential tool for modern biological research applications.

249. (B) Oxford Nanopore
Oxford Nanopore represents a third generation of sequencing technology. It works by passing a single-stranded DNA molecule through a tiny protein pore embedded in a membrane. As each nucleotide passes through the pore, it creates a unique disruption in the electrical current. By analyzing these current fluctuations in real-time, the system can determine the sequence of very long fragments.

250. (A) Both A and R are true and R is the correct explanation of A.
Although next-generation sequencing has taken over large-scale projects, Sanger sequencing remains a vital tool. Its high accuracy for individual sequences makes it the preferred method for verifying results of cloning experiments or confirming specific mutations. For these small-scale applications, the simplicity and reliability of Sanger sequencing often outweigh the high-throughput advantages of more modern and expensive platforms.

251. (A) DNA Footprinting
DNA footprinting is a powerful technique for studying protein-DNA interactions. When a protein binds to a specific DNA sequence, it physically covers that region. If the DNA is then treated with a nuclease like DNase I, the protected region will remain intact. By comparing the digestion patterns of protein-bound and naked DNA on a gel, the binding site is determined.

252. (C) RT-PCR (Reverse Transcription PCR)
Reverse transcription PCR is a modification of the standard PCR technique used to detect and amplify RNA sequences. The process begins with the enzyme reverse transcriptase, which uses the RNA as a template to synthesize a complementary DNA strand. This cDNA is then used as the template for a standard PCR reaction, allowing researchers to study various gene expression patterns.

253. (D) Total amount of DNA in a haploid genome
In genomics, the C-value is a constant that represents the total amount of DNA found in the haploid nucleus of a particular species. This value is usually measured in picograms or in millions of base pairs. While the C-value is characteristic for each species, it does not always reflect the phenotypic complexity or the number of functional genes.

254. (C) Genome size does not tightly correlate with evolutionary complexity.
The C-value paradox describes the surprising observation that there is no consistent relationship between the size of an organism's genome and its

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2. Shift to longer wavelength
3. Shift to shorter wavelength
4. Increased absorption intensity

(A) P-2, Q-3, R-4, S-1
(B) P-3, Q-2, R-1, S-4
(C) P-4, Q-1, R-2, S-3
(D) P-1, Q-4, R-3, S-2

2016

11. Which optical component is specifically responsible for collecting light from the source and focusing it on the specimen?
(A) Condenser
(B) Objective lens
(C) Ocular lens
(D) Phase ring

2007

12. Consider the following statements about numerical aperture (NA):
I. It determines the resolving power of a microscope.
II. It is independent of the refractive index of the medium.
III. A higher NA results in lower resolution.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I only
(C) II and III
(D) I and III

2016

13. Phase-contrast microscopy converts phase shifts in light passing through a transparent specimen into changes in what property?
(A) Wavelength
(B) Frequency
(C) Polarization
(D) Amplitude

2005

14. Which fluorophore is most appropriately paired with its biological application?
(A) DAPI - Lipid membrane tracking
(B) FITC - DNA staining
(C) GFP - Live-cell protein localization
(D) Propidium Iodide - Viable cell nucleus tracking

2003

15. What limits the maximum theoretical resolution of a standard optical microscope to approximately 200 nm?
(A) Significant spherical aberration
(B) The diffraction limit of visible light
(C) Significant chromatic aberration
(D) Inherent photobleaching of the sample

2024

16. In fluorescence microscopy, the dichroic mirror serves which specific function?
(A) Reflects emitted light and transmits excitation light
(B) Absorbs scattered light to improve contrast
(C) Polarizes the excitation light
(D) Reflects excitation light and transmits emitted light

2021

17. The resolving power (d) of a microscope is determined by the equation $d = \frac{0.61\lambda}{NA}$. To maximize resolution, one should:
(A) Decrease the wavelength of light
(B) Increase the wavelength of light
(C) Decrease the numerical aperture
(D) Use a medium with a lower refractive index

2008

18. Which statement about confocal microscopy is INCORRECT?
(A) It eliminates out-of-focus light using a spatial pinhole.
(B) It allows for 3D reconstruction of specimens.
(C) It provides a larger depth of field than widefield microscopy.
(D) It typically uses lasers as an excitation source.

NODIA

2010

19. What is the primary advantage of oil immersion objectives?
(A) They increase numerical aperture by minimizing light refraction
(B) They optimize the refractive index between the lens and specimen
(C) They effectively eliminate the requirement for a condenser lens
(D) They filter out undesirable ultraviolet background radiation

2021

20. Consider the following statements about electron microscopy:
I. TEM uses a beam of electrons transmitted through an ultra-thin specimen.
II. SEM primarily detects secondary electrons for surface topography.
III. Electron microscopes utilize glass lenses to focus the electron beam.
IV. Biological samples for SEM require coating with a heavy metal.
Which of the above statement(s) is/are

homologous genes across different organisms and provides valuable insights into the evolutionary rearrangements, such as translocations, that have occurred since species divergence.

264. (A) Proliferation of retrotransposons and polyploidy events
The enormous variation in genome size among plants is rarely due to differences in the number of essential genes. Instead, most of the variation is driven by two factors: the large-scale duplication of the entire genome, known as polyploidy, and the massive accumulation of repetitive DNA, particularly retrotransposons. These genetic elements can replicate and insert themselves throughout the genome.

265. (B) All RNA transcripts produced by the genome under specific conditions
Transcriptomics is the study of the complete set of RNA molecules, or the transcriptome, within a cell or population of cells. Unlike the genome, which is largely static, the transcriptome is highly dynamic and changes rapidly in response to environmental stimuli, developmental signals, and disease states. By analyzing the transcriptome, researchers gain a comprehensive view of which genes are active.

266. (B) DNA Microarrays
DNA microarrays were the first high-throughput technology for transcriptomics. A microarray consists of a solid surface, such as a glass slide, printed with thousands of microscopic spots of DNA. Each spot contains a specific probe for a different gene. By hybridizing labeled cDNA from a sample onto the array, researchers can simultaneously measure the expression levels of many genes.

267. (A) The gene is equally expressed in both control and treatment conditions.
In a typical two-color microarray experiment, the control sample is labeled with a green dye and the experimental sample with a red dye. When the two samples are hybridized together on the same chip, the resulting color of each spot indicates the relative abundance of that transcript. A yellow spot occurs when equal amounts of both dyes bind.

268. (C) Detects novel transcripts and splice variants without relying on pre-designed probes
While microarrays were once the standard for transcriptomics, they have been largely replaced by RNA-Seq. RNA-Seq uses next-generation sequencing to directly sequence and count every transcript in a sample. This approach is superior because it is more sensitive and does not require prior knowledge of gene sequences. Consequently, RNA-Seq can identify previously unknown genes or alternative splice variants.

269. (D) Alternative splicing and post-translational modifications (PTMs)
Proteomics is significantly more complex than genomics because a single gene does not always equal a single protein. Due to alternative splicing of messenger RNA and the subsequent addition of various post-translational modifications like phosphorylation or glycosylation, one gene can give rise to many different protein isoforms. Understanding this diversity is essential for accurately mapping the functional state of cells.

270. (C) Trypsin
In shotgun proteomics, proteins are too large for direct analysis by mass spectrometry. Therefore, they are first broken down into smaller peptides. The enzyme trypsin is the preferred protease for this task. Trypsin is highly specific and predictable, cleaving the polypeptide chain only at the carboxyl side of the basic amino acids lysine and arginine, resulting in manageable peptides.

271. (B) Isoelectric point (pI) and molecular weight
Two-dimensional gel electrophoresis is a classical technique for separating complex protein mixtures. In the first dimension, proteins are separated by isoelectric focusing along a pH gradient based on their net charge. In the second dimension, proteins are separated perpendicular to the first by SDS-PAGE based on their molecular weight. This two-step process can resolve thousands of individual protein spots.

272. (D) 3' to 5'
Although biological DNA synthesis in cells always proceeds in the five-prime to three-prime direction, chemical synthesis of oligonucleotides in the laboratory follows the opposite path. Using phosphoramidite chemistry on a solid support, nucleotides are added one by one starting from the three-prime end and moving toward the five-

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292. (D) Developing nano-encapsulated "smart" fertilizers for targeted, slow release of nutrients
Nanotechnology offers innovative solutions for improving agricultural efficiency. A major area of research is the development of nano-fertilizers. In these systems, nutrients are encapsulated within tiny nano-scale particles. These smart carriers can be designed to release their contents slowly over time or in response to specific environmental triggers, ensuring that crops receive nutrients when they are needed most.

293. (B) Antisense suppression of the polygalacturonase gene
The Flavr Savr tomato was the first genetically modified food to be sold in grocery stores. Its primary trait was a longer shelf life due to delayed softening. This was achieved by introducing an antisense copy of the gene for polygalacturonase, an enzyme that breaks down cell wall pectin during ripening. This reduced the enzyme's activity for better storage.

294. (C) High-throughput simultaneous detection of multiple plant pathogens in a single assay
Bio-chips and DNA microarrays are becoming valuable tools for plant pathology and diagnostics. These devices contain probes for the unique DNA or RNA sequences of many different viruses, bacteria, and fungi. By testing a single sample from a diseased plant, a bio-chip can simultaneously screen for dozens of possible pathogens. This allows for rapid and accurate disease identification.

295. (D) nptII (Neomycin phosphotransferase II)
Creating a transgenic plant requires a way to identify the few cells that have successfully integrated the new DNA. The nptII gene is the most common selectable marker used for this purpose. It encodes an enzyme that detoxifies the antibiotic kanamycin. When plant tissues are grown on a medium containing kanamycin, only the transgenic cells expressing nptII survive.

296. (A) Specific plant viruses, such as the Papaya Ringspot Virus
RNA interference is a natural defense mechanism that plants use against viral infection. Scientists have exploited this system to create virus-resistant crops. By introducing a small segment of the viral genome into the plant, they can trigger the RNAi pathway to specifically target and degrade the viral RNA upon infection. This approach saved the papaya industry in Hawaii.

297. (B) Using transgenic plants or animals as bioreactors to produce high-value pharmaceutical proteins
Molecular farming, or pharming, is the use of biotechnology to produce pharmaceutical compounds in agricultural organisms. This can include vaccines, antibodies, or therapeutic enzymes. By using plants as bioreactors, companies can produce large quantities of these proteins much more cheaply than with traditional cell culture methods. This technology has the potential to make life-saving drugs more accessible globally.

298. (B) "Disarm" the Ti plasmid by deleting the oncogenes (auxin and cytokinin synthesis genes)
The natural Ti plasmid of Agrobacterium is not suitable for biotechnology because it causes large tumors, or galls, in the plant. To use it as a vector, the plasmid must be disarmed. This involves removing the T-DNA genes responsible for hormone synthesis that cause the disease. Importantly, the border sequences and the virulence genes must be kept intact.

299. (A) Regenerate an entire fertile plant from a single genetically modified somatic cell
The success of plant biotechnology relies on the unique property of totipotency. Unlike animal cells, many differentiated plant cells have the ability to revert to an undifferentiated state and then develop into an entirely new plant. This allows researchers to genetically modify a single cell in culture and then use hormones to stimulate that cell to grow completely.

300. (C) Real-time monitoring of soil conditions, moisture, and crop health parameters
Precision agriculture aims to optimize crop yields while minimizing environmental impact. Nanobiosensors are a key part of this vision. These tiny devices can be deployed throughout a field or even attached to individual plants to provide constant, real-time data on nitrogen levels, water stress, or the presence of pests. This information allows farmers to apply resources accurately.

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NODIA

a distance-matrix method because it starts with a matrix showing the genetic distances between every pair of sequences. The algorithm then iteratively groups the most similar sequences together. While easy to calculate, UPGMA assumes that the rate of evolution is constant across all lineages.

283. (A) Does not assume an equal rate of evolution across all lineages
The neighbor-joining method is a more sophisticated distance-matrix algorithm for phylogenetics. Unlike UPGMA, NJ does not assume a constant molecular clock. This means it can accurately model evolutionary relationships even when different lineages have evolved at different speeds. NJ is widely used because it is computationally efficient and generally produces reliable trees that represent the correct evolutionary topology.

284. (C) An ancestor and all of its descendants
In phylogenetics, a clade is the fundamental unit of classification. It represents a monophyletic group, which is defined as a single common ancestor and every single one of its evolutionary descendants. Clades are identified by shared derived characters that are unique to that group. Identifying clades is essential for understanding the true evolutionary history and relatedness of organisms.

285. (D) Clustal Omega
Multiple sequence alignment is a critical step for identifying conserved functional domains and understanding evolutionary relationships among three or more sequences. Clustal Omega is a widely used program for this purpose. It uses a progressive alignment strategy, starting with the most similar pairs and building the alignment step-by-step. It is known for its speed and accuracy with large datasets.

286. (C) Paralogs
Homology describes genes that share a common ancestry, but there are two distinct ways this can happen. Orthologs are genes in different species that evolved from a single gene in the last common ancestor. Paralogs are genes that arose from a duplication event within the same genome. While orthologs often retain the same function, paralogs frequently evolve new roles.

287. (B) FASTA format
The FASTA format is the universal standard for representing biological sequences in a simple text-based way. Each entry starts with a single-line description that begins with a greater-than symbol. This is followed by the actual sequence of nucleotides or amino acids, which can span multiple lines. Because of its simplicity, FASTA is easily read by almost every bioinformatics program.

288. (D) Assess the confidence or reliability of specific clades within the tree
Bootstrapping is a statistical method used to test the robustness of a phylogenetic tree. It involves randomly re-sampling the original sequence alignment many times to create a set of new pseudo-replicate alignments. A tree is then built for each replicate. The bootstrap value for a specific branch represents the percentage of these trees that contain that same branch.

289. (A) Bacillus thuringiensis
Bt-cotton is a genetically modified crop designed to resist specific insect pests. It contains genes from the soil-dwelling bacterium Bacillus thuringiensis. These genes encode cry proteins, which are crystalline toxins that specifically target the digestive tract of certain insects, such as bollworms. By producing its own insecticide, Bt-cotton reduces the need for external chemical sprays for crop protection.

290. (C) Beta-carotene
Golden Rice is a bio-fortified crop developed to address the humanitarian problem of vitamin A deficiency in developing countries. It was engineered by introducing genes from daffodils and bacteria to complete the biosynthetic pathway for beta-carotene in the rice grain. Beta-carotene is the orange pigment that the human body converts into vitamin A, giving the rice its color.

291. (A) EPSPS gene (CP4 variant)
Glyphosate is a widely used herbicide that works by inhibiting the enzyme EPSPS, which is essential for synthesizing aromatic amino acids in plants. Roundup Ready crops are genetically engineered to be resistant to this herbicide. They carry a specific variant of the EPSPS gene derived from a bacterium. This version of the enzyme is not inhibited by glyphosate treatment.

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prime end. This directionality is required by the specific protecting groups.

273. (A) Dimethoxytrityl (DMT) group
During the chemical synthesis of DNA, it is vital to prevent nucleotides from reacting in an uncontrolled manner. To ensure that only one nucleotide is added at a time, the five-prime hydroxyl group of the incoming monomer is protected with a dimethoxytrityl group. After the coupling reaction is complete, the DMT group is chemically removed to expose the site.

274. (C) LC-MS/MS (Liquid Chromatography-Tandem Mass Spectrometry)
Tandem mass spectrometry coupled with liquid chromatography is the modern standard for identifying the components of protein complexes. After a complex is isolated, it is digested into peptides. These peptides are separated by chromatography and then analyzed by two stages of mass spectrometry. The first stage measures the peptide's mass, and the second stage fragments it for sequence.

275. (A) A known DNA sequence to determine its resultant phenotype by targeted disruption
While forward genetics starts with a phenotype and seeks to find the gene, reverse genetics takes the opposite approach. Driven by the abundance of genome sequence data, reverse genetics starts with a gene of unknown function. Researchers use techniques like gene knockout or site-directed mutagenesis to disrupt the gene and then observe the resulting changes in the organism's phenotype.

276. (D) CRISPR-Cas9
The CRISPR-Cas9 system has revolutionized functional genomics and gene editing. Originally discovered as a mechanism of adaptive immunity in bacteria, it uses a guide RNA to direct the Cas9 nuclease to a specific, matching DNA sequence in the genome. Once there, the enzyme creates a double-strand break. This allows for precise gene disruption or the insertion of sequences.

277. (B) Identify homologous sequences by comparing a query sequence against a database
BLAST is one of the most widely used tools in bioinformatics. It is a heuristic algorithm that allows researchers to rapidly search through massive databases of DNA or protein sequences. By inputting a query sequence, BLAST identifies other sequences that share significant regions of similarity. This helps in predicting the function of a new gene or protein during research.

278. (C) The insertion or deletion of sequences in the alignment
When aligning two sequences, gaps must often be introduced to account for insertions or deletions that occurred during evolution. To prevent the alignment algorithm from creating too many unrealistic gaps, a gap penalty is applied. This penalty reduces the overall alignment score whenever a gap is opened or extended. The algorithm seeks the best balance between matches and gaps.

279. (D) The expected number of random hits with a score equal to or better than the observed score
The E-value is the most important statistical parameter in a BLAST search. It tells the researcher the probability that a particular sequence match occurred by pure chance. A very low E-value, close to zero, indicates that the match is highly significant and likely represents a true evolutionary relationship. Conversely, a high E-value suggests the match might be random.

280. (A) GC content around 40-60%
Designing effective PCR primers requires careful consideration of several parameters. One of the most important is the GC content, which should ideally be between forty and sixty percent. Because guanine-cytosine pairs have three hydrogen bonds, they provide more stability than adenine-thymine pairs. A balanced GC content ensures that the primer will bind specifically and strongly to template DNA.

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281. (B) Complementarity between the 3' ends of the forward and reverse primers
Primer dimers are a common artifact in PCR that can reduce the yield of the desired product. They occur when the forward and reverse primers have complementary sequences at their three-prime ends. This allows the primers to anneal to each other rather than the template. DNA polymerase then extends the primers, creating a short, double-stranded fragment for amplification.

282. (B) Distance-matrix method
UPGMA is a simple clustering algorithm used to construct phylogenetic trees. It is categorized as

CHAPTER 05
Techniques in Biochemistry

2024

1. According to the Beer-Lambert law, absorbance is directly proportional to which of the following?
(A) Concentration and path length
(B) Transmittance and path length
(C) Molar absorptivity and transmittance
(D) Incident light intensity and concentration

2017

2. Which region of the electromagnetic spectrum induces molecular vibrational transitions?
(A) X-ray
(B) Ultraviolet
(C) Infrared
(D) Microwave

2010

3. What is the fundamental cause of a hypsochromic shift in a molecular absorption spectrum?
(A) Change to a less polar solvent
(B) Substitution of an auxochrome
(C) Increase in conjugation
(D) Formation of a molecular dimer

2005

4. In UV-Visible spectroscopy, which electronic transition generally requires the highest energy?
(A) $n \rightarrow \pi$
(B) $\pi \rightarrow \pi$
(C) $n \rightarrow \sigma$
(D) $\sigma \rightarrow \sigma$

2008

5. The fundamental principle of light emission after non-radiative relaxation is associated with which phenomenon?
(A) Absorbance
(B) Fluorescence
(C) Scattering
(D) Refraction

2025

6. Which statement INCORRECTLY describes the relationship between transmittance (T) and absorbance (A)?
(A) $A = \log\left(\frac{1}{T}\right)$
(B) $A = 2 - \log(\%T)$
(C) They are linearly proportional
(D) As transmittance decreases exponentially, absorbance increases linearly

2010

7. What is the primary function of a monochromator in a spectrophotometer?
(A) To detect and count transmitted photons
(B) To amplify the resulting electrical signal
(C) To securely contain the sample solution
(D) To isolate a specific wavelength of light

NODIA

2014

8. The following question consists of two statements — Assertion (A) and Reason (R). Answer this question selecting the appropriate option.
Assertion (A) : Deviations from the Beer-Lambert law often occur at high analyte concentrations.
Reason (R) : High concentrations alter the refractive index of the solution and cause electrostatic interactions between analyte molecules.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2001

9. In the electromagnetic spectrum, which radiation possesses the shortest wavelength and highest frequency?
(A) Radio waves
(B) Gamma rays
(C) Microwaves
(D) Ultraviolet rays

2009

10. Match the items in List I with those in List II.
List I : (Spectroscopic Term)
P. Bathochromic shift
Q. Hypsochromic shift
R. Hyperchromic effect
S. Hypochromic effect
List II : (Definition)
1. Decreased absorption intensity

require prior knowledge of the genome sequence. It uses short, arbitrary primers that bind to various sites in the genome. During PCR, if two primer binding sites are close enough and in the correct orientation, a fragment is amplified. Differences in the resulting banding patterns indicate polymorphisms.

236. (C) Single base pair substitutions
Single nucleotide polymorphisms represent the most common type of genetic variation among individuals of the same species. A SNP occurs when a single nucleotide at a specific position in the genome is changed. While most SNPs are functionally silent, they serve as excellent high-density molecular markers for genetic mapping, disease association studies, and understanding evolutionary history of various populations.

237. (D) Genes with similar functions share conserved DNA sequence homology across species.
Homology-based cloning is a shortcut for isolating genes. It is based on the observation that essential biological functions are often performed by similar proteins in different organisms. Because these proteins are related by evolution, their underlying DNA sequences remain conserved. Researchers can use a known gene from one species as a probe to fish out the related gene.

238. (C) DNA fragments
Southern blotting is a fundamental technique in molecular biology used to detect specific DNA sequences within a complex mixture. The process involves four main steps: separating DNA fragments by size using gel electrophoresis, transferring the fragments onto a solid membrane, hybridizing the membrane with a labeled probe, and finally visualizing the specific bands where the probe has bound.

239. (B) RNA
Northern blotting is an adaptation of the Southern blotting procedure used specifically for the study of RNA. It allows researchers to determine the size of a particular transcript and measure its relative abundance in different tissues or under various experimental conditions. This technique is essential for studying gene expression patterns and identifying alternative splicing events in eukaryotic cells.

240. (B) III, II, I, IV
Positional cloning follows a logical progression. It starts with the phenotypic evaluation of a mapping population to track the trait. Next, researchers identify molecular markers that co-segregate with the trait. Then, high-resolution fine mapping is performed to narrow down the genomic region. Finally, once a candidate gene is identified, its function is confirmed through a complementation test.

241. (A) Absence of a 3'-hydroxyl group
The Sanger sequencing method, also known as the chain-termination method, uses modified nucleotides called dideoxynucleotides. Unlike normal deoxynucleotides, these molecules lack a hydroxyl group at both the two-prime and three-prime positions of the sugar. When a ddNTP is incorporated into a growing DNA chain, the lack of a three-prime hydroxyl prevents addition of further nucleotides, effectively terminating.

242. (C) Fluorescent dye
Modern automated Sanger sequencing has moved away from radioactive labeling. Instead, each of the four chain-terminating dideoxynucleotides is tagged with a different color fluorescent dye. This allows the sequencing reaction to be performed in a single tube. As the DNA fragments pass through a capillary electrophoresis system, a laser detects the color of each fragment's terminal nucleotide accurately.

243. (A) Performing massively parallel sequencing of millions of fragments simultaneously
The revolutionary throughput of next-generation sequencing is due to its ability to perform massively parallel processing. While traditional Sanger sequencing analyzes only one DNA fragment at a time, NGS platforms can simultaneously sequence millions to billions of small DNA fragments in a single run. This massive scaling has dramatically reduced the cost and time required for whole-genome sequencing projects.

244. (D) Sequencing by synthesis with reversible terminators
The Illumina platform is currently the most widely used NGS technology. It utilizes a sequencing by synthesis approach. In each cycle, fluorescently labeled nucleotides with reversible terminators are added. After a nucleotide is incorporated and its color is recorded by a

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INCORRECT?
(A) I, II and IV
(B) III only
(C) II and III
(D) I, III and IV

2025

21. Which heavy metal is commonly used for negative staining of viruses in TEM?
(A) Gold
(B) Uranyl acetate
(C) Silver nitrate
(D) Copper sulfate

2001

22. In Transmission Electron Microscopy (TEM), why must biological specimens be sectioned ultra-thin (typically 50-100 nm)?
(A) To allow secondary electrons to escape
(B) To prevent the electron beam from burning the sample
(C) To allow electrons to pass through the specimen
(D) To facilitate uniform metal coating

2019

23. What is the function of the critical point drying step during SEM sample preparation?
(A) To facilitate protein cross-linking for cellular structure maintenance
(B) To effectively remove excess heavy metal stains from the specimen
(C) To embed the biological tissue securely in a specialized epoxy resin
(D) To avoid surface tension forces that damage sample morphology

2001

24. Which feature is an advantage of Scanning Electron Microscopy (SEM) over Transmission Electron Microscopy (TEM)?
(A) Greater depth of field for 3D surface imaging
(B) Higher absolute magnification capabilities
(C) Ability to visualize internal cellular ultrastructures
(D) Elimination of the need for an internal vacuum

2011

25. Which chemical fixative is most frequently utilized in electron microscopy to preserve fine cellular ultrastructure by cross-linking proteins?
(A) Ethanol
(B) Glutaraldehyde
(C) Acetic acid
(D) Formaldehyde

NODIA

2025

26. In SEM, what is the specific role of the backscattered electron (BSE) detector?
(A) To generate detailed topographic images
(B) To detect differences in atomic number and elemental composition
(C) To focus the primary electron beam
(D) To measure the energy of emitted X-rays

2011

27. What is the typical accelerating voltage used in standard Transmission Electron Microscopy (TEM)?
(A) 1–5 kV
(B) 10–30 kV
(C) 60–120 kV
(D) 500–1000 kV

2015

28. Which component is strictly absent in a basic Scanning Electron Microscope (SEM)?
(A) Electromagnetic lenses
(B) Electron gun
(C) Projection lens
(D) Vacuum system

2021

29. Near-Infrared (NIR) spectroscopy is primarily dependent on which molecular phenomenon?
(A) Fundamental molecular vibrations
(B) Electronic transitions
(C) Nuclear spin flips
(D) Overtone and combination vibrational bands

2013

30. Consider the following statements regarding Raman spectroscopy:
I. It relies on the inelastic scattering of monochromatic light.
II. It measures the absorbance of infrared radiation.
III. Water is a strong Raman scatterer, limiting its biological use.
IV. A change in molecular polarizability is required for a Raman active mode.
V. It provides structural fingerprints of molecules.
Which of the above statement(s) is/are correct?
(A) I, IV and V
(B) II, III and IV
(C) I, II, IV and V
(D) I, III and V

2023

31. Fourier Transform Infrared (FTIR) spectrometers predominantly use which specific interferometer?

(A) Fabry-Perot
(B) Michelson
(C) Mach-Zehnder
(D) Sagnac

2013

32. In UV spectroscopy, which detector uses the photoelectric effect to multiply the current produced by incident light?
(A) Photodiode array
(B) Charge-coupled device
(C) Thermocouple
(D) Photomultiplier tube

2006

33. The specific biochemical application of measuring protein concentration at 280 nm relies on the presence of which amino acids?
(A) Tryptophan and Tyrosine
(B) Glycine and Alanine
(C) Serine and Threonine
(D) Arginine and Lysine

2010

34. Which technique is most directly related to the measurement of molecular rotations and vibrations induced by specific wavelengths?
(A) Visible spectroscopy
(B) UV spectroscopy
(C) IR spectroscopy
(D) Fluorescence spectroscopy

2007

35. Raman spectroscopy differs from IR spectroscopy primarily because Raman relies on:
(A) Change in polarizability
(B) Change in dipole moment
(C) Absorption of photons
(D) Emission of gamma rays

2021

36. Which structural feature of a molecule makes it completely invisible to standard Infrared (IR) spectroscopy?
(A) High molecular weight
(B) Presence of a permanent dipole
(C) Presence of conjugated double bonds
(D) Complete symmetry with no change in dipole during vibration

2004

37. Turbidometry measures the concentration of suspended particles by quantifying what parameter?
(A) Emitted fluorescence
(B) Decrease in transmitted light intensity
(C) Heat generated by particle friction
(D) Intensity of scattered light at a 90-degree angle

2018

38. How does nephelometry fundamentally differ from turbidometry?
(A) It measures transmitted light versus measured fluorescence
(B) It requires the utilization of a radioactive chemical tracer
(C) It measures off-axis scattered light versus straight-line transmission
(D) It is strictly utilized for the analysis of soluble analytes

2002

39. In Atomic Absorption Spectrophotometry (AAS), the flame serves what precise function?
(A) To emit light at the specific wavelength of the analyte
(B) To ionize the sample for mass detection
(C) To detect the concentration of atoms
(D) To atomize the sample into ground-state free atoms

2011

40. The following question consists of two statements — Assertion (A) and Reason (R). Answer this question selecting the appropriate option.
Assertion (A) : Hollow cathode lamps are used as the light source in Atomic Absorption Spectrophotometry.
Reason (R) : They emit a continuous spectrum of light, allowing the detection of multiple elements simultaneously.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

41. Which interference in AAS is caused by the formation of thermally stable compounds in the flame?
(A) Spectral interference
(B) Chemical interference
(C) Ionization interference
(D) Physical interference

2021

42. How is chemical interference (e.g., phosphate interfering with calcium) typically overcome in AAS?

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(A) Decreasing the flame temperature
(B) Adding a releasing agent like lanthanum
(C) Using a different hollow cathode lamp
(D) Diluting the sample with pure water

2021

43. Fluorimetry is significantly more sensitive than standard UV-Vis spectrophotometry primarily because:
(A) Emission is measured against a near-zero dark background.
(B) It measures light absorption over a longer path length.
(C) Fluorescent molecules absorb all wavelengths of light.
(D) It uses higher energy radiation for excitation.

2019

44. What defines the "Stokes shift" in fluorescence spectroscopy?
(A) The time delay between absorption and emission
(B) The quenching of fluorescence by solvent molecules
(C) The difference in wavelength between the excitation and emission maxima
(D) The transition from a singlet to a triplet state

2004

45. In Inductively Coupled Plasma (ICP) techniques, what gas is typically used to generate the plasma?
(A) Nitrogen
(B) Helium
(C) Hydrogen
(D) Argon

2010

46. What is the primary advantage of ICP-MS over ICP-OES?
(A) It has the capability to operate effectively without a high vacuum
(B) It offers significantly lower instrumentation and maintenance costs
(C) It provides lower detection limits and isotopic analysis capability
(D) It provides complete immunity to all known isobaric interferences

2015

47. In MALDI-TOF mass spectrometry, what is the role of the matrix?
(A) To fragment the biomolecules into smaller peptides
(B) To absorb laser energy and facilitate desorption/ionization of the analyte
(C) To act as a stationary phase for molecular separation
(D) To measure the time of flight of the ions

2015

48. The following question consists of two statements — Assertion (A) and Reason (R). Answer this question selecting the appropriate option.
Assertion (A) : NMR spectroscopy is highly effective for elucidating the 3D structure of intact proteins in solution.
Reason (R) : NMR signals are generated by electronic transitions excited by radiofrequency waves.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2017

49. In NMR spectroscopy, chemical shift is universally expressed in which unit?
(A) Parts per million (ppm)
(B) Hertz (Hz)
(C) Wavenumbers ($cm_{\{-1\}}$)
(D) Nanometers (nm)

2004

50. Match the items in List I with those in List II.
List I : (Analytical Technique)
P. ICP-AES
Q. MALDI-TOF
R. NMR
S. AAS
List II : (Key Application)
1. Protein mass determination
2. Trace metal analysis in soil
3. Single element quantification in water
4. Metabolite structure elucidation
(A) P-2, Q-1, R-4, S-3
(B) P-3, Q-1, R-2, S-4
(C) P-4, Q-2, R-1, S-3
(D) P-1, Q-4, R-3, S-2

2013

51. Which atomic nucleus is considered "NMR silent" due to a net nuclear spin of zero?
(A) ^{12}C
(B) ^{1}H
(C) ^{13}C
(D) ^{31}P

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(>50 kb)
(B) Inability to separate proteins
(C) Toxicity of running buffers
(D) Slow running times

2011

98. How does PFGE achieve the resolution of megabase-sized DNA molecules?
(A) By using a very high constant voltage
(B) By using highly concentrated polyacrylamide gels
(C) By periodically alternating the direction of the electric field
(D) By binding DNA to magnetic beads

2024

99. Immunoelectrophoresis combines electrophoresis with which subsequent process?
(A) Double immunodiffusion
(B) Western blotting
(C) Autoradiography
(D) PCR amplification

2007

100. Match the items in List I with those in List II.
List I : (Electrophoresis Technique)
P. SDS-PAGE
Q. IEF
R. PFGE
S. Agarose Electrophoresis
List II : (Target separation)
1. Whole bacterial chromosomes
2. Routine plasmid DNA
3. Denatured protein mass
4. Protein isoelectric point
(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-4, R-1, S-3

2011

101. Which component establishes the stable pH gradient necessary for isoelectric focusing?
(A) Tris-glycine
(B) Carrier ampholytes
(C) Sodium dodecyl sulfate
(D) Acrylamide monomers

2019

102. What is the principle underlying 2D gel electrophoresis?
(A) First dimension separates by size, second by charge
(B) First dimension separates by mass (SDS-PAGE), second by pI (IEF)
(C) First dimension separates by pI (IEF), second by mass (SDS-PAGE)
(D) Both dimensions use SDS-PAGE at different polyacrylamide concentrations

2011

103. In immunoelectrophoresis, the precipitin arcs form where:
(A) Antigen concentration greatly exceeds antibody concentration
(B) The electric field is strongest
(C) The proteins completely denature
(D) Antigen and antibody reach zone of equivalence

2013

104. Relative Centrifugal Force (RCF) is calculated based on which two parameters?
(A) Rotor radius and rotational speed (RPM)
(B) Rotor radius and fluid density
(C) Rotational speed (RPM) and time
(D) Particle size and fluid viscosity

2023

105. The Svedberg unit (S) is a measure of the sedimentation coefficient. One Svedberg is equal to:
(A) 10^{-13} seconds
(B) 10^{-15} seconds
(C) 10^{-9} seconds
(D) 10^{-12} seconds

2024

106. In centrifugation, which of the following best describes the use of a nomogram?
(A) A chemical gradient for separation
(B) A graphical tool to interconvert RPM, RCF, and rotor radius
(C) An equation to calculate fluid viscosity
(D) A type of swinging-bucket rotor

2015

107. A swinging-bucket rotor is generally preferred over a fixed-angle rotor for which specific application?
(A) Density gradient centrifugation
(B) Differential pelleting of whole cells
(C) High-speed pelleting of precipitate
(D) Microcentrifugation of small volumes

2018

108. The sedimentation velocity of a particle in a centrifuge tube does NOT depend on:
(A) Particle mass and density
(B) Density and viscosity of the medium
(C) Ambient light intensity
(D) Applied centrifugal field

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2008

63. Melvin Calvin utilized which radioisotope to trace the path of carbon in photosynthesis?
(A) ^{11}C
(B) ^{14}C
(C) ^{12}C
(D) ^{13}C

2025

64. What is the primary purpose of adding an intensifying screen during X-ray film autoradiography?
(A) To effectively absorb all background stray gamma radiation
(B) To filter out undesirable high-energy beta particle emissions
(C) To prevent the photographic film from drying out during exposure
(D) To convert emission energy into light for enhanced detection

2007

65. The spatial resolution of an autoradiograph is inversely proportional to:
(A) The thickness of the emulsion and energy of the isotope
(B) The half-life of the isotope
(C) The development time
(D) The size of the biological sample

2025

66. Pulse-chase experiments rely on introducing a radiolabeled precursor followed by:
(A) Rapid freezing of the tissue
(B) Addition of a chemical fixative
(C) Washing and adding a large excess of unlabeled precursor
(D) Immediate measurement by scintillation counting

2010

67. Which radioisotope is an Auger electron and gamma ray emitter used heavily in radioimmunoassays (RIA)?
(A) ^{125}I
(B) ^{35}S
(C) ^{14}C
(D) ^{32}P

2014

68. The basic principle of chromatography involves the differential distribution of analytes between:
(A) Two immiscible liquid phases
(B) A solid phase and a gaseous phase only
(C) An ionized phase and a nuclear phase
(D) A stationary phase and a mobile phase

2014

69. In chromatography, the retention factor (R_f) is defined as the ratio of:
(A) Distance traveled by the mobile phase to distance traveled by the analyte
(B) Distance traveled by the analyte to distance traveled by the solvent front
(C) Concentration of analyte in the stationary phase to the mobile phase
(D) Time spent in the mobile phase to time spent in the stationary phase

2016

70. Which of the following represents the correct sequence of elution in normal-phase chromatography?
(A) Polar compounds elute first, followed by non-polar compounds
(B) High molecular weight compounds elute first, followed by low molecular weight
(C) Non-polar compounds elute first, followed by polar compounds
(D) Cations elute first, followed by anions

2001

71. The partition coefficient (K_d) determines separation in partition chromatography. It represents:
(A) The flow rate of the mobile phase
(B) The resistance of the column packing material
(C) The theoretical plate height of the column
(D) The ratio of analyte concentration in the stationary phase to the mobile phase

2016

72. Resolution between two chromatographic peaks depends upon which factors?
(A) Selectivity, efficiency, and retention
(B) Temperature, pressure, and solvent volume
(C) Detector sensitivity, flow rate, and injection volume
(D) Analyte mass, column length, and gravity

2010

73. Paper chromatography separates compounds primarily based on which mechanism?
(A) Ion exchange
(B) Partition
(C) Size exclusion
(D) Affinity binding

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2023

52. Which mass analyzer provides the highest mass resolution and accuracy?
(A) Quadrupole
(B) Time of Flight (TOF)
(C) Ion Trap
(D) Orbitrap

2008

53. The kinetic equation for radioactive decay is mathematically analogous to which order of chemical reaction?
(A) Zero-order
(B) First-order
(C) Second-order
(D) Pseudo-second-order

2003

54. Which radioisotope emits weak beta particles and has a half-life of approximately 12.3 years?
(A) ^{14}C
(B) ^{32}P
(C) ^{3}H
(D) ^{35}S

2016

55. What is the fundamental principle of Liquid Scintillation Counting (LSC)?
(A) Direct detection of particles via a pressurized Geiger-Muller tube
(B) Measurement of the thermal heat generated by radioactive decay
(C) Separation of various isotopes based on their mass-to-charge ratio
(D) Conversion of decay energy into light pulses via a fluor

2019

56. Which radioisotope is most appropriate for pulse-chase labeling of newly synthesized proteins?
(A) ^{35}S
(B) ^{32}P
(C) ^{14}C
(D) ^{45}Ca

2022

57. The phenomenon of "quenching" in Liquid Scintillation Counting results in:
(A) An artificial increase in recorded counts
(B) A reduction in the efficiency of light output detection
(C) Enhanced fluorescence of the primary fluor
(D) Spontaneous emission of alpha particles

2017

58. Calculate the fraction of a radioactive isotope remaining after 3 half-lives.
(A) $\frac{1}{9}$
(B) $\frac{1}{8}$
(C) $\frac{1}{6}$
(D) $\frac{1}{3}$

2025

59. Which radioisotope is a strong beta emitter commonly utilized for radiolabeling nucleic acids and requires thick acrylic shielding?
(A) ^{32}P
(B) ^{3}H
(C) ^{14}C
(D) ^{125}I

2011

60. Match the items in List I with those in List II.
List I : (Radioisotope)
P. ^{32}P
Q. ^{35}S
R. ^{14}C
S. ^{3}H
List II : (Approximate Half-life)
1. 87 days
2. 14.3 days
3. 12.3 years
4. 5730 years
(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-4, Q-3, R-1, S-2
(D) P-2, Q-4, R-1, S-3

2021

61. In autoradiography, beta particles interact with which chemical in the photographic emulsion to form a latent image?
(A) Sodium thiosulfate
(B) Potassium iodide
(C) Uranyl acetate
(D) Silver bromide

2006

62. Which step immediately follows the exposure period during the processing of an autoradiogram?
(A) Fixing
(B) Washing
(C) Developing
(D) Stripping

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2005

86. Isocratic elution in HPLC refers to a process where:
(A) The column temperature is held strictly constant
(B) The flow rate is continuously increased
(C) The mobile phase composition remains unchanged throughout the run
(D) Multiple detectors are used simultaneously

2014

87. Which HPLC detector measures the refractive index of the eluent and is considered a "universal" but low-sensitivity detector?
(A) UV-Vis absorbance detector
(B) Fluorescence detector
(C) Electrochemical detector
(D) Refractive Index (RI) detector

2019

88. The theoretical plate number (N) of a chromatographic column is an indicator of:
(A) The separation efficiency of the column
(B) The column's physical length
(C) The maximum pressure the column can withstand
(D) The volume of the mobile phase required

2023

89. Electrophoretic mobility of a molecule in an electric field is directly proportional to its:
(A) Frictional coefficient
(B) Net charge
(C) Molecular radius
(D) Mass

2001

90. The following question consists of two statements — Assertion (A) and Reason (R). Answer this question selecting the appropriate option.
Assertion (A) : In SDS-PAGE, proteins migrate toward the anode strictly based on their molecular weight.
Reason (R) : Sodium Dodecyl Sulfate binds to proteins, denaturing them and imparting a uniform negative charge-to-mass ratio.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2012

91. In agarose gel electrophoresis of nucleic acids, what is the role of ethidium bromide?
(A) It intercalates between DNA base pairs and fluoresces under UV light.
(B) It acts as a running buffer to maintain pH.
(C) It provides a high density to the sample for well loading.
(D) It degrades RNA to prevent interference.

2001

92. The discontinuous buffer system in SDS-PAGE uses a stacking gel primarily to:
(A) Separate high molecular weight proteins
(B) Dissolve insoluble membrane proteins
(C) Concentrate protein samples into a sharp band before separation
(D) Visualize the proteins during the run

2017

93. Native gel electrophoresis differs from denaturing gel electrophoresis because it separates proteins based on:
(A) Molecular weight only
(B) Isoelectric point only
(C) Hydrophobicity only
(D) A combination of charge, mass, and 3D conformation

2019

94. What is the role of beta-mercaptoethanol or dithiothreitol (DTT) in SDS-PAGE sample preparation?
(A) To visualize the migrating front
(B) To alkylate free sulfhydryl groups
(C) To reduce disulfide bonds
(D) To maintain physiological pH

2015

95. Isoelectric focusing (IEF) separates proteins strictly on the basis of their:
(A) Molecular weight
(B) Isoelectric point (pI)
(C) Hydrodynamic radius
(D) Sequence homology

2002

96. In an IEF gel, a protein will stop migrating when it reaches a pH region where its net charge is:
(A) Highly negative
(B) Highly positive
(C) Equilibrated with the ampholytes
(D) Zero

2003

97. Pulsed-Field Gel Electrophoresis (PFGE) was developed specifically to overcome what limitation of standard agarose gel electrophoresis?
(A) Inability to resolve very large DNA fragments

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2005

74. In Thin-Layer Chromatography (TLC), silica gel acts as a stationary phase due to its:
(A) Highly hydrophobic surface
(B) Highly polar surface containing silanol groups
(C) Porous nature allowing size exclusion
(D) Ability to conduct electrical current

2001

75. In two-dimensional TLC, the plate is rotated 90 degrees after the first run. What is the primary purpose of this technique?
(A) To resolve complex mixtures that overlap in a single dimension
(B) To increase the speed of the separation
(C) To measure the molecular weight of the analytes
(D) To allow detection by UV light

2013

76. Which visualization reagent is broadly used in TLC to detect amino acids?
(A) Iodine vapor
(B) Potassium permanganate
(C) Ninhydrin
(D) Ethidium bromide

2021

77. In standard gravity-flow column chromatography, what force drives the mobile phase through the stationary phase bed?
(A) A high-pressure mechanical pump
(B) Capillary action
(C) Electroosmotic flow
(D) Hydrostatic pressure (gravity)

2005

78. Which functional group is utilized in strong anion exchange chromatography?
(A) Sulfonate
(B) Carboxylate
(C) Quaternary ammonium
(D) Phenyl

2005

79. Size-exclusion chromatography separates molecules primarily according to their:
(A) Isoelectric point
(B) Hydrodynamic volume
(C) Net charge
(D) Hydrophobicity

2010

80. Arrange the following steps of an affinity chromatography protocol in the correct order:
I. Elution of the target protein
II. Equilibration of the column
III. Washing away unbound proteins
IV. Application of the sample
(A) II, IV, III, I
(B) IV, II, III, I
(C) II, III, IV, I
(D) I, II, IV, III

2019

81. In Gas Chromatography (GC), the mobile phase is typically an inert gas such as:
(A) Helium or Nitrogen
(B) Oxygen or Carbon Dioxide
(C) Methane or Ethane
(D) Hydrogen chloride or Ammonia

2015

82. Which detector is virtually universal for organic compounds in Gas Chromatography?
(A) Electron Capture Detector (ECD)
(B) Thermal Conductivity Detector (TCD)
(C) Flame Ionization Detector (FID)
(D) Photoionization Detector (PID)

2025

83. High-Performance Liquid Chromatography (HPLC) columns are typically packed with highly uniform, small-diameter particles (e.g., 3-5 μm) to:
(A) Increase mass transfer and column efficiency
(B) Decrease the operating pressure
(C) Allow gravity flow of the mobile phase
(D) Prevent chemical degradation of analytes

2018

84. In reversed-phase HPLC, the stationary phase is typically:
(A) Unmodified silica
(B) Alumina
(C) Diethylaminoethyl (DEAE) cellulose
(D) C18 (Octadecylsilane) modified silica

2016

85. Which statement represents an INCORRECT pairing of a chromatography technique and its primary separation basis?
(A) Ion-exchange chromatography - Net charge
(B) Reversed-phase HPLC - Molecular shape and size
(C) Affinity chromatography - Specific biological interaction
(D) Gas-liquid chromatography - Volatility and partition

NODIA

2011

109. Which rotor type provides the shortest path length and fastest pelleting time?
(A) Swinging-bucket rotor
(B) Fixed-angle rotor
(C) Zonal rotor
(D) Vertical tube rotor

2023

110. Consider the following statements about differential centrifugation:
I. It separates particles primarily based on differences in sedimentation rate.
II. Successive steps utilize decreasing centrifugation speeds.
III. It results in a highly pure final fraction in a single step.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2003

111. In isopycnic (equilibrium density gradient) centrifugation, particles separate strictly based on their:
(A) Size
(B) Buoyant density
(C) Shape
(D) Frictional coefficient

2025

112. Consider the following statements about density gradient centrifugation:
I. Rate-zonal centrifugation separates particles by size and mass.
II. Isopycnic centrifugation requires the gradient density to exceed the particle density.
III. Sucrose is commonly used for rate-zonal gradients.
IV. Cesium chloride (CsCl) is typically used for isopycnic separation of DNA.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) II, III and IV
(C) I, III and IV
(D) I, II and III

2012

113. During a classic subcellular fractionation by differential centrifugation, which organelle typically pellets first at low speeds (~600 x g)?
(A) Nuclei
(B) Mitochondria
(C) Ribosomes
(D) Microsomes

2007

114. Rate-zonal centrifugation requires the sample to be loaded:
(A) Mixed evenly throughout the gradient
(B) At the absolute bottom of the tube
(C) As a thin layer on top of a pre-formed gradient
(D) Without any density gradient medium present

2021

115. Ultracentrifuges operate at very high speeds, necessitating which built-in physical condition to prevent rotor overheating due to air friction?
(A) A high vacuum chamber
(B) A high-pressure nitrogen atmosphere
(C) Submersion in liquid nitrogen
(D) Continuous water flushing

2003

116. Which gradient material is best suited for the isopycnic separation of intact cells without inducing osmotic shock?
(A) Cesium chloride
(B) Sucrose
(C) Glycerol
(D) Percoll or Ficoll

2001

117. Analytical ultracentrifugation is distinct from preparative ultracentrifugation because it:
(A) Does not use a vacuum system
(B) Continuously monitors sedimentation in real-time via optical systems
(C) Requires much larger sample volumes
(D) Operates at significantly lower speeds

2012

118. In vitro plant tissue culture relies heavily on the concept of cellular "totipotency", which is defined as:
(A) The ability of a cell to undergo rapid apoptosis
(B) The biological fusion of two specific protoplasts
(C) The capacity of a plant cell to regenerate a fertile plant
(D) The capability of a cell to produce secondary metabolites

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2024

119. Which essential component in standard plant tissue culture media acts as the primary carbon and energy source?
(A) Agar
(B) Ammonium nitrate
(C) Kinetin
(D) Sucrose

2016

120. Consider the following statements about plant growth regulators in tissue culture:
I. High auxin to cytokinin ratio promotes root formation.
II. High cytokinin to auxin ratio promotes shoot formation.
III. Equal ratios of auxin and cytokinin generally induce unorganized callus growth.
IV. Gibberellins are primarily used to induce somatic embryogenesis.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and IV
(C) I, III and IV
(D) I, II and IV

2018

121. The most common gelling agent used to solidify in vitro culture media is:
(A) Gelatin
(B) Agar
(C) Pectin
(D) Alginate

2007

122. Surface sterilization of plant explants is commonly achieved using which chemical agent?
(A) Indole-3-acetic acid
(B) Sodium hypochlorite
(C) Polyethylene glycol
(D) Colchicine

2007

123. Anther or microspore culture is primarily used in plant biotechnology to generate:
(A) Haploid or double-haploid homozygous lines
(B) Triploid seedless plants
(C) Genetically engineered chimeras
(D) Viral-free rootstocks

2011

124. Consider the following elements used in Murashige and Skoog (MS) media:
I. Nitrogen
II. Phosphorus
III. Potassium
IV. Iron
V. Zinc
Which of the above constitute the "macronutrients"?
(A) I, II and III
(B) I, II, III and IV
(C) II, III, IV and V
(D) I, III, IV and V

2002

125. The production of pathogen-free (virus-free) plants is most effectively achieved through which specific culture technique?
(A) Protoplast culture
(B) Callus culture
(C) Suspension culture
(D) Meristem culture

2009

126. Protoplast isolation typically requires the enzymatic digestion of the plant cell wall using:
(A) Protease and lipase
(B) Amylase and chitinase
(C) Cellulase and pectinase
(D) Lysozyme and DNase

NODIA

2015

127. Somatic embryogenesis differs from organogenesis in that:
(A) Somatic embryos develop direct vascular connections with the surrounding maternal callus.
(B) Somatic embryogenesis generates bipolar structures having both shoot and root axes.
(C) Organogenesis is a process that occurs strictly and exclusively from haploid tissues.
(D) Somatic embryos are unique in that they cannot be converted into viable artificial seeds.

2002

128. What is the fundamental goal of cryopreservation in biological systems?
(A) To facilitate rapid selection of cold-tolerant mutants
(B) To intentionally lyse cells for organelle extraction
(C) To effectively sterilize samples prior to tissue culture
(D) To halt metabolic processes for long-term cell viability

2010

129. During slow cooling in cryopreservation, what is the primary cause of cell death?
(A) Severe osmotic dehydration and solute

toxicity
(B) Intracellular ice formation
(C) Protein denaturation by high heat
(D) Loss of the cell wall

2019

130. Consider the following statements about cryoprotectants:
I. They lower the freezing point of the medium.
II. DMSO is a penetrating cryoprotectant.
III. Sucrose is a non-penetrating cryoprotectant.
IV. They are highly toxic at room temperature.
V. They encourage rapid intracellular ice crystallization.
Which of the above statement(s) is/are correct?
(A) I, II, III and IV
(B) II, III, IV and V
(C) I, III, IV and V
(D) I, II, IV and V

2013

131. The temperature of liquid nitrogen, standardly used for long-term cryopreservation, is approximately:
(A) $-80^{\circ}C$
(B) $-130^{\circ}C$
(C) $-196^{\circ}C$
(D) $-273^{\circ}C$

2015

132. Vitrification in cryopreservation refers to the process of:
(A) Forming large and uniform intracellular ice crystals
(B) Thawing the sample rapidly in a heated water bath
(C) Substituting cell water with absolute liquid ethanol
(D) Transitioning water into an amorphous solid glass phase

2009

133. Which parameter must be precisely optimized to avoid lethal intracellular ice crystal formation during a two-step freezing protocol?
(A) The concentration of atmospheric oxygen
(B) The cooling rate ($^{\circ}C/\min$)
(C) The intensity of ambient light
(D) The pH of the liquid nitrogen

2003

134. Which chemical is universally recognized as a penetrating cryoprotectant in mammalian cell culture?
(A) Polyethylene glycol (PEG)
(B) Trehalose
(C) Dimethyl sulfoxide (DMSO)
(D) Polyvinylpyrrolidone (PVP)

2007

135. For the recovery of viable cells after cryopreservation, the thawing process must typically be:
(A) Very slow, at $4^{\circ}C$
(B) Gradual, in a stepwise manner
(C) Performed inside a microwave
(D) Rapid, in a $37^{\circ}C$ water bath

2019

136. The following question consists of two statements — Assertion (A) and Reason (R). Answer this question selecting the appropriate option.
Assertion (A) : Vitrification requires extremely high concentrations of cryoprotectants compared to slow-freezing protocols.
Reason (R) : High solute concentrations prevent ordered hydrogen bonding, preventing ice lattice formation even at ultralow temperatures.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2022

137. Which tissue is generally most recalcitrant to successful cryopreservation due to high water content and structural complexity?
(A) Pollen grains
(B) Direct fleshy fruit tissues
(C) Zygotic embryos
(D) Apical shoot meristems

2001

138. The primary function of a thermal cycler in the Polymerase Chain Reaction (PCR) is to:
(A) Rapidly alternate block temperatures to facilitate denaturation, annealing, and extension
(B) Synthesize oligonucleotide primers
(C) Provide a template-independent DNA polymerase activity
(D) Quantify the accumulated DNA product via fluorescence

2017

139. In a standard PCR cycle, what occurs during the denaturation step (typically $94-96^{\circ}C$)?
(A) Double-stranded DNA template separates into single strands

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Membrane Transfer → Hybridization
(C) Electrophoresis → Restriction Digestion → Hybridization → Membrane Transfer
(D) Membrane Transfer → Hybridization → Restriction Digestion → Electrophoresis

2008

161. DNA barcoding in animals predominantly targets a specific region of which mitochondrial gene?
(A) Cytochrome c oxidase subunit I (COI)
(B) 16S rRNA
(C) RNA polymerase II
(D) Ribulose-1,5-bisphosphate carboxylase

2009

162. The primary objective of conducting a phylogenetic analysis using molecular data is to:
(A) Predict the future evolutionary trajectory of a species
(B) Determine the tertiary structure of proteins
(C) Reconstruct the evolutionary relationships and common ancestry among taxa
(D) Measure the exact metabolic rate of an organism

2019

163. Which mathematical model algorithm is widely used to construct phylogenetic trees based on molecular sequence alignments?
(A) Maximum Likelihood
(B) Fast Fourier Transform
(C) Student's t-test
(D) Analysis of Variance (ANOVA)

2015

164. In phylogenetic tree topology, an "outgroup" is defined as:
(A) The most highly evolved taxon in the clade
(B) A species with the longest DNA sequence
(C) A node representing a speciation event
(D) A taxon known to be completely unrelated, serving to root the tree

2011

165. Northern blotting is specifically utilized for the detection and quantification of:
(A) Specific DNA sequences
(B) Specific RNA molecules
(C) Specific proteins
(D) Carbohydrate structures

2010

166. In Western blotting, what specific probe is used to identify the target molecule on the membrane?
(A) A radiolabeled complementary DNA strand
(B) A fluorescent RNA aptamer
(C) An enzyme-conjugated specific antibody
(D) Ethidium bromide

2023

167. Capillary transfer in a standard Southern blot draws buffer upwards through the gel and membrane via:
(A) An applied electric field
(B) Vacuum suction
(C) Centrifugal force
(D) Capillary action using highly absorbent paper towels

2024

168. Which membrane material is most commonly preferred for nucleic acid transfer due to its high binding capacity and physical durability?
(A) Nitrocellulose or Nylon
(B) Polyvinylidene fluoride (PVDF) only
(C) Filter paper (Cellulose)
(D) Agarose

2002

169. What is the crucial purpose of the "blocking" step in a Western blot protocol?
(A) To prevent the primary antibody from degrading
(B) To saturate non-specific binding sites on the membrane with a generic protein
(C) To cross-link proteins to the membrane permanently
(D) To denature the target protein completely

2009

170. Arrange the following steps of a Western blot in the correct sequence:
I. SDS-PAGE
II. Membrane Transfer
III. Addition of Substrate for Detection
IV. Primary Antibody Incubation
V. Secondary Antibody Incubation
(A) I, II, IV, V, III
(B) II, I, IV, V, III
(C) I, II, V, IV, III
(D) I, IV, V, II, III

2019

171. A "sandwich" ELISA requires which specific combination of reagents?
(A) Immobilized capture antibody, target antigen, enzyme-linked detection antibody
(B) Immobilized antigen, primary antibody, enzyme-linked secondary antibody
(C) Target antigen mixed with enzyme-linked antigen, immobilized primary antibody

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Q. RAPD
R. AFLP
S. SSR (Microsatellites)

List II : (Key Characteristic)

1. Relies on tandem repeat length variation
2. Non-PCR based, relies on restriction enzymes
3. Uses arbitrary decamer primers
4. Combines restriction digestion and PCR adapter ligation

(A) P-2, Q-3, R-4, S-1
(B) P-1, Q-4, R-2, S-3
(C) P-4, Q-1, R-3, S-2
(D) P-3, Q-2, R-1, S-4

2006

151. Which molecular marker is distinctly "codominant," allowing heterozygotes to be distinguished from homozygotes?
(A) RAPD
(B) ISSR
(C) AFLP
(D) SSR (Microsatellites)

2006

152. Amplified Fragment Length Polymorphism (AFLP) analysis involves two consecutive PCR amplifications known as:
(A) Pre-amplification and selective amplification
(B) Reverse and forward PCR
(C) Asymmetric and symmetric PCR
(D) Nested and multiplex PCR

2007

153. What makes Simple Sequence Repeats (SSRs) highly polymorphic among individuals of the same species?
(A) Point mutations occurring at high rates in coding regions
(B) Varying repeat unit counts due to replication slippage
(C) Frequent large-scale chromosomal inversions in genome
(D) Transposon activity resulting in deletion of repeat loci

2007

154. A major limitation of the RAPD technique is:
(A) It requires extensive prior knowledge of the genome sequence
(B) It has low reproducibility between different laboratories
(C) It can only detect codominant alleles
(D) It requires highly radioactive reagents

2001

155. Single Nucleotide Polymorphisms (SNPs) represent what type of genetic variation?
(A) A single base pair substitution at a specific locus
(B) Insertion of long terminal repeats
(C) Variation in ploidy level
(D) Deletion of entire gene families

2013

156. In plant breeding, molecular markers closely linked to a trait of interest are used to indirectly select for the trait. This process is called:
(A) Gene Cloning
(B) Somaclonal variation
(C) Marker-Assisted Selection (MAS)
(D) Mutagenesis

2024

157. Cleaved Amplified Polymorphic Sequences (CAPS) markers are generated by:
(A) Performing AFLP without the restriction step
(B) Hybridizing a random probe to a Southern blot
(C) Sequencing the entire genome
(D) Amplifying a specific locus via PCR followed by restriction enzyme digestion

2021

158. Ribotyping is a molecular typing technique that characterizes bacterial strains based on variations in:
(A) Plasmid copy number
(B) Peptidoglycan cell wall structure
(C) The 16S and 23S rRNA gene operons
(D) Flagellar proteins

2009

159. Mitochondrial DNA (mtDNA) profiling is heavily utilized in phylogenetic and evolutionary studies primarily because:
(A) It undergoes widespread recombination during meiosis
(B) It is strictly maternally inherited in most animals and lacks recombination
(C) It possesses a significantly slower mutation rate than nuclear DNA
(D) It codes for all essential cellular proteins

2022

160. Which of the following represents the correct sequence of steps in Southern blotting?
(A) Hybridization → Restriction Digestion → Electrophoresis → Membrane Transfer
(B) Restriction Digestion → Electrophoresis →

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2024

204. In regression analysis, the "method of least squares" determines the best-fitting line by minimizing the sum of the squares of the:
(A) X values
(B) Y values
(C) Residuals (vertical distances from points to the line)
(D) Slopes

2003

205. Which condition indicates a negative linear correlation?
(A) As X increases, Y remains constant.
(B) As X increases, Y increases proportionally.
(C) The scatterplot forms a perfect circle.
(D) As X increases, Y decreases proportionally.

2002

206. Regression analysis differs conceptually from correlation analysis because regression:
(A) Assumes neither variable is dependent
(B) Calculates the exact identical metric as correlation
(C) Establishes a predictive functional relationship mapping an independent variable to a dependent variable
(D) Is restricted solely to categorical data

2023

207. A simple linear regression slope of zero implies that:
(A) There is a perfect linear relationship
(B) The dependent variable Y does not change linearly as a function of X
(C) The Y-intercept is also zero
(D) X is the sole cause of Y

2011

208. The principle underlying fluorescence emission dictates that the emitted photon always possesses:
(A) Higher energy and shorter wavelength than the excitation photon
(B) Identical energy to the excitation photon
(C) Variable energy independent of excitation
(D) Lower energy and longer wavelength than the excitation photon

2012

209. In fluorescence microscopy, photobleaching refers to:
(A) The irreversible photochemical destruction of a fluorophore
(B) The reversible shifting of emission wavelength
(C) The enhancement of signal by adjusting laser power
(D) The binding of the dye to non-target structures

2010

210. Consider the following statements about confocal microscopy:
I. It utilizes a pinhole aperture strictly in the excitation path.
II. It utilizes a pinhole aperture in the emission path to block out-of-focus light.
III. It generates optical sections that can be stacked for 3D reconstruction.
Which of the above statement(s) is/are correct?
(A) I and III
(B) II and III
(C) I and II
(D) I only

2001

211. Which electron microscopy technique allows visualization of the natural, hydrated state of a biological macromolecular complex without chemical fixation or staining?
(A) Cryo-Electron Microscopy (Cryo-EM)
(B) Standard TEM
(C) Standard SEM
(D) Scanning Tunneling Microscopy

NODIA

2011

212. Consider the following statements regarding Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES):
I. It utilizes an argon plasma operating at temperatures up to 10,000 K.
II. It detects photons emitted by excited atoms returning to the ground state.
III. It suffers from severe chemical interference compared to AAS.
IV. It allows for simultaneous multi-element analysis.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) II, III and IV
(C) I, II and III
(D) I, III and IV

2022

213. In Nuclear Magnetic Resonance (NMR) spectroscopy, Spin-Spin Coupling (J-coupling) provides information primarily about:
(A) The exact molecular weight
(B) The number of adjacent, NMR-active nuclei
(C) The ionization potential of the molecule
(D) The concentration of the sample

(D) Immobilized capture antigen, enzyme-linked target antibody

2005

172. In an indirect ELISA for detecting serum antibodies, what is initially coated onto the microtiter plate wells?
(A) The patient's serum
(B) The enzyme-conjugated secondary antibody
(C) The specific target antigen
(D) The stopping solution

2012

173. Microarray technology fundamentally relies on which molecular principle to detect targets in a sample?
(A) Polymerase chain amplification
(B) Antigen-antibody interaction
(C) Restriction enzyme digestion
(D) Nucleic acid hybridization

2015

174. In a two-color DNA microarray experiment for gene expression profiling, the competitive hybridization utilizes cDNA labeled with:
(A) ^{32}P and ^{35}S
(B) SYBR Green and TaqMan probes
(C) Cy3 (green) and Cy5 (red) fluorophores
(D) Biotin and Digoxigenin

2019

175. What is the fundamental difference between a DNA microarray and an RNA-Seq experiment?
(A) Microarrays measure protein; RNA-Seq measures mRNA.
(B) Microarrays rely on known probe sequences; RNA-Seq provides sequence data for all transcripts present.
(C) Microarrays are purely qualitative; RNA-Seq is purely qualitative.
(D) Microarrays do not require nucleic acid extraction.

2024

176. Which enzyme conjugate is most commonly used in ELISA detection systems to produce a colorimetric signal?
(A) Taq polymerase
(B) Ribonuclease A
(C) Restriction endonuclease EcoRI
(D) Horseradish peroxidase (HRP)

2006

177. A protein microarray spotted with various specific antibodies is best suited for:
(A) High-throughput profiling of protein abundance in a sample
(B) Determining DNA sequence
(C) Quantifying mRNA expression levels
(D) Measuring enzymatic reaction rates

2002

178. What determines the analytical sensitivity limit of a conventional competitive ELISA?
(A) The physical size of the plate wells
(B) The wavelength of the plate reader
(C) The affinity constant of the specific antibody used
(D) The volume of the wash buffer

NODIA

2025

179. In descriptive biostatistics, which measure of central tendency is most severely affected by extreme outlier values?
(A) Arithmetic Mean
(B) Median
(C) Mode
(D) Geometric Mean

2010

180. Standard Deviation (SD) fundamentally quantifies what characteristic of a dataset?
(A) The average value of the entire dataset
(B) The magnitude of the most frequent value
(C) The precision of the sample mean relative to the population mean
(D) The average degree of dispersion or spread around the mean

2008

181. Variance is mathematically related to standard deviation as:
(A) Variance is the square root of standard deviation
(B) Variance is the square of standard deviation
(C) Variance is standard deviation divided by sample size
(D) They are independent parameters

2019

182. How does Standard Error (SE) differ conceptually from Standard Deviation (SD)?
(A) SE measures the variability of individual data points, SD measures sample mean variability.
(B) SD is for normally distributed data only, SE is for skewed data.
(C) SD measures dispersion in a sample; SE estimates the precision with which the sample mean estimates the population mean.
(D) SE is always numerically larger than SD.

2024

183. The formula for the standard error of the mean (SEM) is:

(A) $\frac{SD}{n}$

(B) $\frac{SD}{\sqrt{n}}$

(C) $\frac{Variance}{\sqrt{n}}$

(D) $\frac{Mean}{SD}$

2021

184. In a strictly normal distribution, approximately what percentage of observations fall within plus or minus two standard deviations ($\pm 2SD$) from the mean?

(A) 50%

(B) 68%

(C) 95%

(D) 99%

2009

185. The Coefficient of Variation (CV) is a standardized measure of dispersion calculated as:

(A) $\left(\frac{Mean}{SD}\right) \times 100$

(B) $\left(\frac{SD}{Mean}\right) \times 100$

(C) $\left(\frac{Variance}{Mean}\right) \times 100$

(D) $\left(\frac{SD}{n}\right) \times 100$

2022

186. The following question consists of two statements — Assertion (A) and Reason (R). Answer this question selecting the appropriate option.

Assertion (A) : The standard error of the mean decreases as the sample size increases.

Reason (R) : The sample size (n) is in the denominator of the standard error formula, causing the value to shrink as n grows.

(A) Both A and R are true and R is the correct explanation of A.

(B) Both A and R are true but R is not the correct explanation of A.

(C) A is true but R is false.

(D) A is false but R is true.

2015

187. Which parameter provides a unitless measure allowing for the comparison of relative variability between two distinctly different metrics (e.g., plant height in cm vs. grain yield in kg)?

(A) Coefficient of Variation

(B) Standard Error

(C) Variance

(D) Standard Deviation

2006

188. Degrees of freedom (df) for the total variance in a dataset of n observations is equal to:

(A) n

(B) $n-1$

(C) $n-2$

(D) $\frac{n}{2}$

2013

189. Analysis of Variance (ANOVA) is primarily used to test hypotheses regarding differences among:

(A) Three or more sample variances

(B) Two sample proportions

(C) A single correlation coefficient

(D) Three or more sample means

2016

190. Match the items in List I with those in List II.

List I : (ANOVA Term)

P. Total Sum of Squares

Q. Mean Square

R. F-ratio

S. p-value

List II : (Definition)

1. Ratio of between-group to within-group variance
2. Sum of squares divided by degrees of freedom
3. Overall variation in the data
4. Probability of observing the data if the null hypothesis is true

(A) P-4, Q-3, R-1, S-2

(B) P-3, Q-2, R-1, S-4

(C) P-2, Q-1, R-4, S-3

(D) P-1, Q-4, R-2, S-3

2013

191. In a one-way ANOVA, the F-statistic is calculated as the ratio of:

(A) Mean Square Within / Mean Square Between

(B) Sum of Squares Between / Sum of Squares Within

(C) Mean Square Between / Mean Square Within

(D) Total Sum of Squares / Mean Square Error

2001

192. The null hypothesis (H_0) for a standard one-way ANOVA assumes that:

(A) All group variances are zero.

(B) At least one group mean is significantly different.

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(C) The data is not normally distributed.
(D) All group means are statistically equal.

2010

193. If an ANOVA test yields a p-value of 0.015 at a significance level (α) of 0.05, the correct conclusion is:
(A) Reject the null hypothesis
(B) Accept the null hypothesis
(C) Conclude that all means are equal
(D) The test is inconclusive

2018

194. Which assumption is NOT inherently required to perform a valid standard ANOVA?
(A) Independence of observations
(B) Homogeneity of variances among groups
(C) A linear relationship between two variables
(D) Normal distribution of residuals

2006

195. What does the "Mean Square Error" (MSE) or "Within-Group Mean Square" estimate in an ANOVA table?
(A) The random or unexplained inherent variability within the populations
(B) The variability due strictly to the treatment effects
(C) The sum of the treatment means
(D) The degrees of freedom

2016

196. When an ANOVA indicates a significant difference among treatment groups, which subsequent test is commonly used to identify exactly which groups differ?
(A) Chi-square test
(B) F-test
(C) Pearson correlation
(D) Post-hoc test (e.g., Tukey's HSD)

2016

197. A randomized complete block design (RCBD) ANOVA partitions total variance into which three components?
(A) Treatments, Replicates, and Grand Mean
(B) Treatments, Blocks, and Error
(C) Rows, Columns, and Error
(D) Main plot, Sub-plot, and Error

2001

198. The Pearson product-moment correlation coefficient (r) quantifies:
(A) The non-linear association between two variables
(B) The cause-and-effect relationship between an independent and dependent variable
(C) The strength and direction of the linear relationship between two continuous variables
(D) The difference between two group means

2023

199. What are the strict theoretical bounds for the correlation coefficient (r)?
(A) 0 to 1
(B) 0 to 100
(C) -1 to +1
(D) $-\infty$ to $+\infty$

2001

200. Consider the following statements about linear correlation:
I. A correlation of +0.90 indicates a strong positive linear relationship.
II. A correlation of 0 indicates the complete absence of any mathematical relationship.
III. Correlation directly implies causation.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I only
(D) I and III

NODIA

2022

201. If the coefficient of correlation between crop yield and rainfall is $r = 0.80$, the coefficient of determination (R^2) is:
(A) 0.20
(B) 0.64
(C) 0.80
(D) 1.60

2002

202. The coefficient of determination (R^2) is formally interpreted as:
(A) The standard deviation of the residuals
(B) The proportion of variance in the dependent variable predictable from the independent variable
(C) The slope of the regression line
(D) The exact probability of the null hypothesis

2002

203. In a simple linear regression equation $Y = a + bX$, the term b represents:
(A) The slope of the regression line
(B) The Y-intercept
(C) The correlation coefficient
(D) The standard error of the estimate

(B) Primers anneal to the template
(C) Taq polymerase extends the new strand
(D) The DNA template is entirely degraded

2016

140. The following question consists of two statements — Assertion (A) and Reason (R). Answer this question selecting the appropriate option.
Assertion (A) : Taq DNA polymerase is fundamental to modern PCR because it survives the high temperature required for DNA denaturation.
Reason (R) : Taq polymerase is extracted from a psychrophilic bacterium found in Arctic glaciers.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2023

141. The annealing temperature (T_a) in a PCR reaction is generally set:
(A) $10^{\circ}C$ above the melting temperature of the primers
(B) At the extension temperature of Taq polymerase ($72^{\circ}C$)
(C) At exactly $50^{\circ}C$ regardless of primer sequence
(D) $3-5^{\circ}C$ below the lowest melting temperature (T_m) of the primers

2019

142. A crucial requirement for effective PCR primer design is to avoid:
(A) A G/C content between 40-60%
(B) A length of 18-22 nucleotides
(C) Primer dimers and hairpin structures
(D) A G/C clamp at the 3' end

2001

143. If a PCR reaction starts with one double-stranded DNA molecule, theoretically, how many double-stranded molecules are present after 30 cycles?
(A) 30^2
(B) $2^{\{30\}}$
(C) 60
(D) $30^{\{10\}}$

2014

144. In real-time quantitative PCR (qPCR), SYBR Green dye functions by:
(A) Quenching the fluorescence of a TaqMan probe
(B) Hydrolyzing single-stranded RNA
(C) Acting as an alternative DNA polymerase
(D) Binding specifically to double-stranded DNA and emitting fluorescence

2024

145. What is the essential role of Magnesium ions (Mg^{2+}) in the PCR buffer?
(A) It functions as an essential cofactor for Taq DNA polymerase activity.
(B) It lowers the melting temperature of the DNA.
(C) It degrades template RNA.
(D) It prevents the primers from forming dimers.

2008

146. Which DNA polymerase possesses strong 3' to 5' exonuclease (proofreading) activity, offering higher fidelity than Taq polymerase?
(A) Klenow fragment
(B) DNA Polymerase I
(C) Pfu polymerase
(D) Reverse Transcriptase

2008

147. Reverse Transcription PCR (RT-PCR) is utilized to synthesize and amplify cDNA starting from which template?
(A) RNA
(B) Genomic DNA
(C) Plasmid DNA
(D) Mitochondrial DNA

2023

148. Restriction Fragment Length Polymorphism (RFLP) markers depend on the variation in:
(A) Length of short tandem repeats
(B) Random primer binding sites
(C) RNA alternative splicing
(D) Presence or absence of restriction endonuclease recognition sites

2005

149. Random Amplified Polymorphic DNA (RAPD) is a PCR-based marker technique that uses:
(A) Highly specific primer pairs for known genes
(B) A single short, arbitrary primer
(C) Restriction enzyme digestion followed by adapter ligation
(D) Radioactive probes for Southern hybridization

2003

150. Match the items in List I with those in List II.
List I : (Molecular Marker)
P. RFLP

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2009

214. Which specific parameter does a Time-of-Flight (TOF) mass analyzer measure to determine the mass-to-charge ($\frac{m}{z}$) ratio?
(A) The degree of deflection in a magnetic field
(B) The frequency of ion oscillation in a quadrupole
(C) The time taken for accelerated ions to travel through a field-free flight tube
(D) The absorbance of laser energy

2011

215. The half-life ($t_{\frac{1}{2}}$) of a radioactive isotope undergoing first-order decay is related to the decay constant (λ) by the equation:
(A) $t_{1/2} = \ln(2)/\lambda$
(B) $t_{1/2} = \lambda/\ln(2)$
(C) $t_{1/2} = \lambda \times \ln(2)$
(D) $t_{1/2} = 1/\lambda$

2023

216. Phosphorimaging offers distinct advantages over standard film autoradiography, most notably:
(A) It offers a significantly wider linear dynamic range for quantification
(B) It requires a much longer exposure time
(C) It strictly detects alpha particles
(D) It eliminates the need to use radioisotopes entirely

2019

217. In partition chromatography, tailing of peaks is most commonly caused by:
(A) Injecting too little sample
(B) Non-linear isotherms due to unwanted secondary interactions (e.g., active silanol groups)
(C) Excessive column temperature
(D) Very low flow rates

2017

218. In Gas Chromatography, increasing the column oven temperature ramp rate generally results in:
(A) Increased retention times and broader peaks
(B) Decreased retention times and decreased resolution
(C) Complete destruction of the stationary phase
(D) A transition to liquid chromatography

2023

219. Electrophoresis in a polyacrylamide gel relies on a matrix formed by the polymerization of acrylamide with the cross-linking agent:
(A) N,N'-methylenebisacrylamide (Bis-acrylamide)
(B) Ammonium persulfate (APS)
(C) Tetramethylethylenediamine (TEMED)
(D) Sodium dodecyl sulfate (SDS)

2002

220. Consider the following statements about Agarose Gel Electrophoresis:
I. Lower percentage agarose gels are used to resolve very small DNA fragments.
II. Migration speed is inversely proportional to the log10 of molecular weight.
III. Supercoiled plasmid DNA migrates faster than linear DNA of the same mass.
IV. The gel is run horizontally in a continuous buffer system.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and IV
(C) I, III and IV
(D) I, II and IV

NODIA

2016

221. An isopycnic gradient is distinct from a rate-zonal gradient because the isopycnic gradient:
(A) Separates particles purely based on their mass
(B) Requires a significantly lower rotor speed
(C) Assumes the particles will eventually pellet at the bottom
(D) Reaches a steady state where further centrifugation time does not alter band position

2004

222. When establishing an Agrobacterium-mediated plant transformation, tissue culture is vital for:
(A) Synthesizing the T-DNA
(B) Degrading the bacterial cell wall
(C) Selecting and regenerating whole transgenic plants from transformed single cells
(D) Sequestering secondary metabolites

2011

223. Somaclonal variation refers to the occurrence of phenotypic and genotypic variation:
(A) Exclusively in zygotic embryos
(B) Induced by Agrobacterium infection
(C) Created by specific targeted genome editing
(D) Arising spontaneously among plants regenerated from long-term in vitro tissue cultures

2015

224. Consider the following statements regarding cryopreservation:
I. Vitrification entirely bypasses the formation

of a crystalline ice phase.

II. Highly concentrated cryoprotectants are toxic and must be rapidly removed upon thawing.

III. Controlled slow-freezing typically cools at $1^{\circ}C$ per minute.

IV. Liquid nitrogen vapor phase storage is generally at $-80^{\circ}C$.

V. Thawing should be performed slowly on ice to prevent thermal shock.

Which of the above statement(s) is/are correct?

(A) I, II and III
(B) I, III and IV
(C) II, IV and V
(D) I, II and V

2018

225. A key difference between standard PCR and Real-Time qPCR is that qPCR:

(A) Quantifies the initial template concentration by monitoring amplification during the exponential phase
(B) Does NOT require DNA polymerase
(C) Runs at a constant isothermal temperature
(D) Detects the product only at the final plateau phase

2001

226. In qPCR, the Cycle Threshold (C_t) value represents:

(A) The total number of cycles run
(B) The temperature required to melt the amplicon
(C) The cycle number at which the fluorescent signal clearly exceeds the background threshold
(D) The time required to design the primers

2003

227. Restriction endonucleases naturally function in bacteria as:

(A) A defense mechanism against invading viral (phage) DNA
(B) Enzymes required for lagging strand DNA synthesis
(C) Topoisomerases regulating DNA supercoiling
(D) Ribozymes that cleave mRNA

2014

228. Which type of molecular marker is strictly classified as a dominant marker, unable to distinguish heterozygotes?

(A) SSR
(B) RFLP
(C) SNP
(D) RAPD

2022

229. Internal Transcribed Spacer (ITS) regions of ribosomal DNA are frequently sequenced in phylogenetics to resolve relationships at which taxonomic level?

(A) Kingdom level
(B) Species or generic level
(C) Phylum level
(D) Domain level

2011

230. During a Southern hybridization, stringency is strictly controlled by manipulating:

(A) Gel percentage and voltage during electrophoresis
(B) The specific activity of the radioactive isotope
(C) Temperature and salt concentration of the wash buffer
(D) The size of the membrane

2001

231. The primary purpose of using Denhardt's solution during the pre-hybridization step of a Southern blot is to:

(A) Cleave the DNA template
(B) Label the probe with radioactivity
(C) Elute the DNA off the membrane
(D) Block non-specific nucleic acid binding sites on the nylon membrane

2019

232. To detect a specific protein interaction via far-Western blotting, the probe utilized is:

(A) A purified, labeled interacting partner protein
(B) A specific monoclonal antibody
(C) A specific radiolabeled DNA sequence
(D) A carbohydrate binding lectin

2017

233. The technique known as ELISPOT was specifically developed to measure:

(A) The exact molecular weight of an antigen
(B) The frequency of individual cells secreting a specific protein (e.g., cytokine)
(C) The DNA sequence of an antibody gene
(D) The size of a viral particle

2009

234. In descriptive statistics, which metric is calculated by taking the nth root of the product of n values?

(A) Arithmetic mean

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(B) Geometric mean
(C) Harmonic mean
(D) Median

2008

235. If the variance of a dataset is 144, what is the standard deviation?
(A) 12
(B) 14.4
(C) 72
(D) 20736

2018

236. The assumption of "homoscedasticity" in linear regression dictates that:
(A) The variables are perfectly correlated
(B) The independent variable is normally distributed
(C) The residuals have a constant variance across all levels of the independent variable
(D) The regression line passes through the origin

2013

237. Which non-parametric statistical test is considered the equivalent of the independent two-sample t-test?
(A) Kruskal-Wallis test
(B) Wilcoxon signed-rank test
(C) Spearman's rank correlation
(D) Mann-Whitney U test

2013

238. In a normal distribution, the Mean, Median, and Mode are:
(A) Distinctly separate values
(B) Completely unrelated
(C) Exactly equal
(D) Inversely proportional

2021

239. The concept of "multicollinearity" in multiple regression analysis refers to:
(A) High correlation between the dependent and independent variables
(B) High correlation among two or more independent variables
(C) A non-linear relationship in the data
(D) Non-normal distribution of residuals

2010

240. Which of the following represents the correct sequence for hypothesis testing in ANOVA?
(A) Calculate F-statistic → Formulate Null Hypothesis → Compare to Critical F → Determine p-value
(B) Formulate Null Hypothesis → Calculate F-statistic → Compare to Critical F → Conclude
(C) Compare to Critical F → Calculate F-statistic → Formulate Null Hypothesis → Conclude
(D) Formulate Null Hypothesis → Compare to Critical F → Calculate F-statistic → Conclude

2024

241. To assess the interaction effect between two distinct categorical independent variables on a continuous dependent variable, which test is appropriate?
(A) Two-way ANOVA
(B) One-way ANOVA
(C) Simple linear regression
(D) Chi-square test of independence

2009

242. In a scatter plot assessing linear correlation, if data points strictly follow a horizontal line, the correlation coefficient (r) is:
(A) +1.0
(B) -1.0
(C) 0.0
(D) Undefined

NODIA

2002

243. When designing primers for PCR, the inclusion of a "GC clamp" refers to:
(A) Placing one or two G or C bases at the 3' end to ensure tight binding at the extension site
(B) Synthesizing the entire primer exclusively with G and C bases
(C) Using a chemical clamp to prevent primer degradation
(D) Adding a restriction site sequence to the 5' end

2012

244. The resolving power of an agarose gel can be increased for small DNA fragments by:
(A) Increasing the voltage significantly
(B) Decreasing the agarose concentration
(C) Adding SDS to the running buffer
(D) Increasing the agarose concentration

2006

245. Fluorescent in situ hybridization (FISH) is distinct from Southern blotting because it detects specific nucleic acid sequences:
(A) After total DNA is transferred to a nylon membrane
(B) Inside intact cells or chromosomes without

depth of the sample, confocal systems effectively reduce the depth of field to a single focal plane.

19. (A) They increase numerical aperture by minimizing light refraction
Oil immersion objectives utilize a specialized oil with a refractive index similar to that of glass. By replacing the air gap between the cover slip and the objective lens, the oil prevents the refraction or bending of light rays as they exit the specimen. This allows a greater cone of light to enter the lens, significantly increasing the numerical aperture.

20. (B) III only
Electron microscopy uses a beam of electrons instead of light to achieve much higher resolution. While transmission electron microscopy passes electrons through samples, scanning electron microscopy detects secondary electrons from surfaces. Crucially, these systems use electromagnetic lenses to focus the electron beam, as glass lenses are opaque to electrons. Proper sample preparation, including heavy metal coating for surface topography, is required.

21. (B) Uranyl acetate
Negative staining is a technique in transmission electron microscopy used to visualize small biological objects like viruses or proteins. The specimen is embedded in a thin film of a heavy metal salt, such as uranyl acetate. This dense stain surrounds the particles but does not penetrate them, creating a high-contrast image where the biological structures appear light against a dark background.

22. (C) To allow electrons to pass through the specimen
In transmission electron microscopy, the electron beam must pass completely through the specimen to form an image on the detector. Because electrons have relatively low penetrating power, biological samples must be cut into ultra-thin sections, typically between fifty and one hundred nanometers. If sections are too thick, the electrons will be absorbed or scattered, resulting in a dark, indistinct image.

23. (D) To avoid surface tension forces that damage sample morphology
Critical point drying is a vital step in preparing biological samples for scanning electron microscopy. It involves replacing the water in the cells with a specialized liquid, such as carbon dioxide, and then raising the temperature and pressure to the critical point. This allows the liquid to transition to a gas phase without crossing a phase boundary, avoiding damaging surface tension.

24. (A) Greater depth of field for 3D surface imaging
Scanning electron microscopy offers a significant advantage over transmission electron microscopy regarding its ability to provide three-dimensional views of surface topographies. Due to its unique scanning mechanism, it possesses a large depth of field, allowing for the visualization of complex, irregular surfaces with great clarity. In contrast, transmission electron microscopy is primarily used for viewing internal cellular structures within thin sections.

25. (B) Glutaraldehyde
Glutaraldehyde is a powerful dialdehyde commonly used as a chemical fixative in electron microscopy. It functions by forming covalent cross-links between the amino groups of neighboring protein molecules, effectively stabilizing the fine cellular ultrastructure and preventing post-mortem degradation. This rapid and thorough fixation is essential for preserving the delicate spatial arrangements of organelles and membranes before the sample undergoes dehydration and embedding.

26. (B) To detect differences in atomic number and elemental composition
The backscattered electron detector in scanning electron microscopy is sensitive to the atomic number of the elements present in the specimen. Heavier elements with higher atomic numbers reflect more electrons than lighter elements, resulting in brighter areas on the image. This allows researchers to distinguish between different materials or chemical compositions within a sample based on their relative brightness and contrast.

27. (C) 60–120 kV
Standard transmission electron microscopes typically operate at accelerating voltages ranging between sixty and one hundred twenty kilovolts. This voltage provides the electrons with sufficient energy to penetrate ultra-thin biological sections while maintaining a wavelength small enough to achieve high resolution. While higher voltages are used for thicker samples or materials

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(D) Step gradient using Ficoll-Paque

2005

257. What characterizes a "continuous" cell line in mammalian tissue culture?
(A) It has undergone transformation to become immortalized and divide indefinitely.
(B) It ceases division after 50 generations due to senescence.
(C) It requires no specific nutrient media.
(D) It is maintained permanently at $-20^{\circ}C$.

2014

258. During Agrobacterium tumefaciens infection, which specific region of the Ti plasmid is transferred into the plant host genome?
(A) The entire Ti plasmid
(B) The vir (virulence) region
(C) The T-DNA (Transferred DNA) region
(D) The ori (origin of replication)

2013

259. The enzyme Reverse Transcriptase is technically classified as a:
(A) RNA-dependent DNA polymerase
(B) DNA-dependent DNA polymerase
(C) RNA-dependent RNA polymerase
(D) DNA-dependent RNA polymerase

2017

260. The following question consists of two statements — Assertion (A) and Reason (R). Answer this question selecting the appropriate option.
Assertion (A) : In gas chromatography, highly volatile compounds generally elute earlier than less volatile compounds.
Reason (R) : Highly volatile compounds have a lower boiling point and partition more readily into the gaseous mobile phase.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2011

261. The specific property of Taq DNA polymerase that facilitates the TA cloning method is:
(A) Its 3' to 5' proofreading activity
(B) Its ability to add a single 3'-adenine overhang to PCR products
(C) Its function as a ligase
(D) Its inherent resistance to restriction enzymes

2003

262. During molecular phylogenetic analysis, "bootstairs" is performed to:
(A) Increase the speed of the alignment algorithm
(B) Root the phylogenetic tree
(C) Provide a statistical confidence assessment for the branching clades in the tree
(D) Determine the exact chronological time of speciation

2012

263. When identifying an unknown protein via Mass Spectrometry, the generated fragmentation data is most commonly mapped to theoretical spectra using which process?
(A) Edman Degradation
(B) Isoelectric focusing
(C) Circular Dichroism
(D) Peptide Mass Fingerprinting

2012

264. Interaction where an unlabelled primary antibody binds the target, and a labeled secondary antibody binds the primary antibody, defines which assay format?
(A) Indirect Immunofluorescence
(B) Direct Immunofluorescence
(C) Competitive ELISA
(D) Sandwich ELISA

2008

265. What fundamental issue limits the quantification of target DNA in the "plateau phase" of a standard PCR reaction?
(A) Primers degrade completely after 10 cycles.
(B) Amplification efficiency drops dramatically due to reagent depletion and product inhibition.
(C) The DNA polymerase begins to degrade the product.
(D) The template spontaneously mutates.

2004

266. Which technique is most appropriately designed to measure the genome-wide binding sites of a specific transcription factor?
(A) RNA-Seq
(B) ChIP-Seq (Chromatin Immunoprecipitation Sequencing)
(C) ATAC-Seq
(D) Whole Genome Bisulfite Sequencing

2008

267. In flow cytometry, "Forward Scatter" (FSC) primarily provides information regarding the cell's:

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(A) Relative size
(B) Internal granularity
(C) DNA content
(D) Surface protein expression

2004

268. In flow cytometry, "Side Scatter" (SSC) is primarily indicative of the cell's:
(A) Relative size
(B) Membrane potential
(C) Internal complexity or granularity
(D) Apoptotic state

2001

269. The specific use of DAPI in fluorescence applications is due to its strong, selective binding to:
(A) G-C rich regions in double-stranded DNA
(B) Single-stranded RNA
(C) Phospholipid bilayers
(D) A-T rich regions in double-stranded DNA

2005

270. A standard curve in quantitative biochemical assays maps:
(A) Time versus temperature
(B) Molecular weight against isoelectric point
(C) Known analyte concentrations against their corresponding measured analytical signals
(D) The rate of an enzyme reaction against pH

2002

271. In statistics, when calculating the sample variance, why is the sum of squared deviations divided by $n-1$ instead of n?
(A) To make the resulting variance value significantly smaller
(B) To provide an unbiased estimate of the population variance
(C) To simplify calculations involving the mathematical square root
(D) Because one data point is discarded to standardize the set

2001

272. A regression line that best fits a dataset according to the Ordinary Least Squares (OLS) criterion must always pass exactly through:
(A) The origin (0,0)
(B) The first and last data points
(C) The median of both sets
(D) The point representing the mean of X and the mean of Y $(\bar{X}, \bar{Y})$

2015

273. The primary reason for performing a data transformation (e.g., logarithmic or arcsine transformation) prior to ANOVA is to:
(A) Ensure the data meets the assumptions of normality and homogeneity of variance
(B) Make non-significant p-values significant
(C) Convert all values to percentages
(D) Increase the sample size artificially

2019

274. In a two-dimensional plot, the dependent variable is conventionally plotted on the:
(A) X-axis (Abscissa)
(B) Z-axis
(C) Y-axis (Ordinate)
(D) Either axis interchangeably

2007

275. If two variables demonstrate a completely deterministic mathematical relationship, their coefficient of correlation (r) will theoretically be:
(A) Exact +1.0 or exact -1.0
(B) Exactly 0.0
(C) Infinity
(D) Undefined

NODIA

2013

276. In an experimental block design, the primary function of "blocking" is to:
(A) Arbitrarily increase the error variance of the experiment
(B) Provide a logical substitute for experimental randomization
(C) Effectively eliminate the inherent need for replication
(D) Control known variability to reduce error variance

2025

277. The term "heteroscedasticity" in linear regression implies that:
(A) The model predicts perfectly.
(B) The error terms do not have constant variance.
(C) The data follows a normal distribution.
(D) The predictor variable is categorical.

2009

278. Which statement about the median is inherently correct?
(A) It is the exact arithmetic average of all values.
(B) It is the most frequently occurring value in the dataset.
(C) It divides a ranked dataset perfectly into two

equal halves.
(D) It is heavily skewed by single extreme outliers.

2006

279. The Interquartile Range (IQR) is mathematically defined as the difference between:
(A) The maximum and minimum values
(B) The mean and the median
(C) The third quartile (Q3) and the first quartile (Q1)
(D) Two standard deviations above and below the mean

2017

280. Match the items in List I with those in List II.
List I : (Chromatography Detector)
P. Flame Ionization
Q. Refractive Index
R. Photodiode Array
S. Mass Spectrometer
List II : (Technique)
1. UV-Vis HPLC
2. Gas Chromatography
3. Ultimate molecular identification
4. Isocratic HPLC with poor UV absorption
(A) P-2, Q-4, R-1, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-4, Q-3, R-2, S-1
(D) P-3, Q-1, R-4, S-2

2025

281. The term "multiplex PCR" refers to a technique in which:
(A) Multiple templates are tested in separate tubes simultaneously.
(B) Multiple distinct primer pairs are used in a single reaction tube to amplify multiple targets.
(C) A single primer is used to amplify multiple regions.
(D) PCR is combined with an ELISA step.

2012

282. The resolution in a mass spectrometer is strictly defined as its capability to:
(A) Measure the exact physical size of the ion
(B) Differentiate between two ions with closely identical mass-to-charge ($\frac{m}{z}$) ratios
(C) Detect the lowest absolute concentration of an analyte
(D) Operate at standard atmospheric pressure

2009

283. In ultracentrifugation, the sedimentation coefficient of a biological macromolecule depends heavily on its shape; an elongated protein compared to a spherical protein of identical mass will sediment:
(A) Slower, due to a higher frictional coefficient
(B) Faster, due to increased density
(C) At the identical speed
(D) Exclusively at the meniscus

2005

284. Which non-radioactive detection system relies on an antibody specific to a small steroid molecule incorporated into a nucleic acid probe?
(A) Biotin-Streptavidin system
(B) Ethidium Bromide system
(C) Digoxigenin (DIG) system
(D) Fluorescein system

2014

285. In plant biotechnology, the "Gene Gun" (Biolistic transformation) delivers DNA into cells by:
(A) Electroporating the cell membrane
(B) Utilizing viral vectors
(C) Chemically treating protoplasts with PEG
(D) Coating DNA onto tungsten or gold microparticles and firing them at high velocity

2004

286. Somatic hybridization involves the fusion of:
(A) A sperm cell and an egg cell in vitro
(B) Two haploid pollen grains
(C) Protoplasts derived from somatic cells of two different plant species
(D) Callus tissue with a bacterial cell

2024

287. Which chemical is universally recognized for promoting cell fusion during somatic hybridization?
(A) Sodium chloride
(B) Polyethylene glycol (PEG)
(C) Glutaraldehyde
(D) Indole-3-butyric acid (IBA)

2023

288. Synthetic seeds (artificial seeds) are produced by encapsulating which tissue in a protective gel like calcium alginate?
(A) Zygotic embryos
(B) Unfertilized ovules
(C) Pollen grains
(D) Somatic embryos or shoot buds

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2021

289. Acclimatization (or hardening) is a critical final step in plant tissue culture necessary because in vitro plantlets:
(A) Possess poorly developed cuticular wax and non-functional stomata
(B) Have excessive root systems
(C) Are generally heavily contaminated with fungi
(D) Lack chloroplasts completely

2024

290. What specific role does an "adjuvant" play when injected alongside an antigen for generating polyclonal antibodies?
(A) It degrades the antigen to prevent toxicity.
(B) It specifically targets the antigen to the liver.
(C) It enhances the host's immune response to the antigen without being antigenic itself.
(D) It prevents the primary immune response to allow a stronger secondary response.

2004

291. Hybridoma technology is the standard method used strictly for the production of:
(A) Monoclonal antibodies
(B) Recombinant DNA vaccines
(C) Polyclonal antibodies in rabbit serum
(D) Synthetic peptides

2008

292. In hybridoma generation, B-cells are fused with myeloma cells. What crucial property does the myeloma cell impart to the resulting hybridoma?
(A) The specific antibody sequence
(B) The ability to survive in HAT medium
(C) The capacity to bind the target antigen
(D) Immortality in cell culture

2010

293. The purpose of using HAT (Hypoxanthine-Aminopterin-Thymidine) medium in hybridoma technology is to:
(A) Provide essential nutrients for standard B-cell growth
(B) Selectively kill unfused myeloma cells while allowing hybridomas to survive
(C) Prevent bacterial contamination
(D) Induce rapid somatic hypermutation

2007

294. Which class of immunoglobulins represents the most abundant antibody in human serum and is standardly utilized in secondary detection assays?
(A) IgM (B) IgA
(C) IgG (D) IgE

2004

295. Polyclonal antibodies represent a diverse pool of antibodies targeting:
(A) A single identical epitope on a single antigen
(B) DNA rather than protein
(C) Lipids exclusively
(D) Multiple distinct epitopes on the same antigen

2001

296. A completely balanced chemical equation for the reduction of MTT or XTT in a cellular viability assay primarily indicates the activity of:
(A) Mitochondrial oxidoreductase enzymes
(B) Nuclear DNA polymerase
(C) Cytosolic ribosomes
(D) Lysosomal proteases

2004

297. In biostatistics, the term "bivariate data" describes an experimental dataset containing:
(A) Only two observations in total
(B) Exactly two distinct variables measured for each observational unit
(C) Two separate groups being compared for a single metric
(D) A probability distribution with two identical modes

NODIA

2016

298. Which measure quantifies the unstandardized linear dependence (joint variability) of two variables, forming the numerator of the correlation equation?
(A) Standard Deviation
(B) Covariance
(C) Sum of Squares
(D) Residual Error

2002

299. If the correlation between variable X and variable Y is strictly zero, the corresponding linear regression line for Y on X will be:
(A) A horizontal line with a slope of zero
(B) A vertical line
(C) A line with a slope of exactly 1
(D) Curved non-linearly

2013

300. The mathematical equation describing the relationship between variance (s^2) and standard deviation (s) of a sample is:
(A) $s = \frac{s^2}{n}$

(B) $s = \sqrt{s^2}$

(C) $s = \left(s^2\right)^2$

(D) $s = \log\left(s^2\right)$

****

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prior extraction
(C) Using purely enzymatic colorimetric reactions without fluorescence
(D) Utilizing RNA exclusively

2006

246. What fundamentally distinguishes High-Resolution Melt (HRM) analysis from standard qPCR melt curves?
(A) It requires the use of ethidium bromide.
(B) It melts RNA rather than DNA.
(C) It can detect single nucleotide variations (SNPs) based on minuscule differences in melting temperature.
(D) It requires no fluorescent dye.

2016

247. The term "isobaric interference" in ICP-MS refers to:
(A) Blockage of the plasma torch by solid particles
(B) Signal loss due to high vacuum pressure
(C) Complete overlap of atomic emission spectral lines
(D) Polyatomic ions that share the identical mass-to-charge ratio as the target analyte

2001

248. Flow cytometry differs from standard fluorimetry largely because it measures:
(A) The fluorescence of single cells passing individually through a laser beam
(B) Radioactivity rather than fluorescence
(C) The total bulk fluorescence of a cuvette
(D) Absorbance exclusively

2010

249. Which of the following is NOT a standard measure of dispersion in descriptive biostatistics?
(A) Range
(B) Harmonic Mean
(C) Standard Error
(D) Variance

2017

250. Arrange the typical workflow steps for an RNA-Seq experiment in the correct order:
I. Library preparation
II. RNA extraction
III. Sequencing
IV. Data mapping to reference genome
(A) II, I, III, IV
(B) I, II, III, IV
(C) II, III, I, IV
(D) I, III, II, IV

2003

251. The "Type I error" in statistical hypothesis testing corresponds to:
(A) Rejecting a true null hypothesis
(B) Failing to reject a false null hypothesis
(C) Calculating the mean incorrectly
(D) Having a sample size that is too small

2015

252. Statistical power is mathematically defined as:
(A) The probability of making a Type I error (α)
(B) The probability of avoiding a Type I error ($1-\alpha$)
(C) The probability of correctly rejecting a false null hypothesis ($1-\beta$)
(D) The probability of making a Type II error (β)

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2012

253. Which microscopy technique utilizes a specialized prism (Wollaston prism) to generate pseudo-3D images with high contrast based on optical path length gradients?
(A) Fluorescence Microscopy
(B) Darkfield Microscopy
(C) Scanning Electron Microscopy
(D) Differential Interference Contrast (DIC) Microscopy

2002

254. In chromatography, the Van Deemter equation models plate height (H) as a function of:
(A) Column length
(B) Temperature
(C) Mobile phase linear velocity
(D) Analyte concentration

2011

255. The term "eddy diffusion" (the A term in the Van Deemter equation) accounts for band broadening caused by:
(A) Longitudinal diffusion in the mobile phase
(B) Multiple distinct flow paths around packing particles of varying size
(C) The resistance to mass transfer in the stationary phase
(D) Thermal gradients within the column

2018

256. Which gradient provides the highest resolution for separating mononuclear cells from whole blood?
(A) Continuous sucrose gradient
(B) Continuous cesium chloride gradient
(C) Plain buffered saline without gradient

shortest wavelengths and the highest frequencies. According to the Planck-Einstein relation, energy is directly proportional to frequency; therefore, gamma rays possess the highest energy per photon. These properties distinguish them from other regions like radio waves, which have the longest wavelengths and the lowest frequency and energy.

10. (A) P-2, Q-3, R-4, S-1
Spectroscopic shifts describe changes in the absorption characteristics of a molecule. A bathochromic shift moves the absorption maximum toward longer wavelengths, while a hypsochromic shift moves it toward shorter wavelengths. Furthermore, a hyperchromic effect refers to an increase in the molar absorptivity or intensity of absorption. Conversely, a hypfocusing effect signifies a reduction in the intensity of the light absorbed.

11. (A) Condenser
The condenser is an essential optical component located beneath the microscope stage. Its primary function is to collect divergent light rays from the illumination source and concentrate them into a uniform, focused cone of light onto the specimen. Proper adjustment of the condenser ensures optimal illumination, contrast, and resolution, which are critical for obtaining a clear image at high magnifications.

12. (B) I only
Numerical aperture is a dimensionless value that characterizes the range of angles over which an optical system can accept or emit light. It is a critical factor in determining the resolving power of a microscope lens. Increasing the numerical aperture allows the objective to capture more diffraction orders, thereby improving the fine detail or resolution of the resulting biological image.

13. (D) Amplitude
Phase-contrast microscopy utilizes the differences in refractive index and thickness within transparent, unstained biological specimens. As light passes through these structures, it undergoes subtle phase shifts relative to the surrounding medium. This specialized optical system uses an annular diaphragm and a phase plate to convert these invisible phase variations into visible changes in light intensity or amplitude for visualization.

14. (C) GFP - Live-cell protein localization
Green Fluorescent Protein is a versatile bioluminescent tool widely utilized in cell biology to study protein localization and dynamics in living systems. Unlike chemical dyes that may be toxic, this protein can be genetically fused to a target protein, allowing researchers to track its movement and expression in real-time. It remains stable and emits bright green light when excited by blue light.

15. (B) The diffraction limit of visible light
The resolution of a standard optical microscope is fundamentally constrained by the wave nature of light, a principle known as the diffraction limit. According to Abbe's law, features smaller than approximately half the wavelength of the light used cannot be resolved. For visible light, this theoretical limit is roughly two hundred nanometers, preventing the visualization of smaller sub-cellular structures.

16. (D) Reflects excitation light and transmits emitted light
A dichroic mirror is a specialized color filter used in fluorescence microscopy to selectively reflect or transmit light based on wavelength. It is designed to reflect the shorter excitation wavelengths toward the specimen while allowing the longer emitted fluorescence wavelengths to pass through to the detector. This separation is crucial for ensuring that only the emitted signal reaches the final image.

17. (A) Decrease the wavelength of light
The resolving power of a microscope indicates its ability to distinguish between two closely spaced points. Based on the resolution equation, decreasing the wavelength of the light used for illumination directly improves the resolution by making the distance value smaller. Alternatively, increasing the numerical aperture of the objective lens or the refractive index of the medium also enhances the fine structural detail.

18. (C) It provides a larger depth of field than widefield microscopy.
Confocal microscopy provides superior image quality by using a spatial pinhole to exclude out-of-focus light from the detector. This allows for precise optical sectioning of thick specimens, enabling the three-dimensional reconstruction of biological structures. Unlike widefield microscopy, which captures light from the entire

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ANSWERS

1. (A) Concentration and path length
The Beer-Lambert law establishes a linear relationship between the absorbance of a solution and its properties. Absorbance depends on the concentration of the absorbing species and the distance the light travels through the sample. When either the concentration or the path length increases, the number of interacting molecules increases, leading to a proportional rise in measured absorbance.

2. (C) Infrared
Infrared radiation corresponds to the energy range required to excite vibrational modes within molecular bonds. When a molecule absorbs infrared light, it undergoes transitions between discrete vibrational energy levels. This specific interaction depends on changes in the molecular dipole moment during vibration. Higher energy regions like ultraviolet induce electronic transitions, while lower energy microwave radiation affects molecular rotation.

3. (A) Change to a less polar solvent
A hypsochromic shift represents a displacement of the absorption maximum toward shorter wavelengths, often called a blue shift. This phenomenon occurs when a change in solvent polarity or molecular environment increases the energy gap between electronic states. Specifically, transitioning to a less polar solvent can stabilize the ground state more than the excited state, requiring higher excitation energy.

4. (D) $\sigma \rightarrow \sigma^*$
Electronic transitions involve the movement of electrons between molecular orbitals upon absorbing light. Transitions from bonding sigma orbitals to antibonding sigma orbitals represent the highest energy gap in organic molecules. These transitions typically occur in the vacuum ultraviolet region because of the extreme stability of sigma bonds. Other transitions like n to pi star require significantly less energy to occur.

5. (B) Fluorescence
Fluorescence is a photoluminescence process where a molecule absorbs light at a specific wavelength and subsequently emits light at a longer wavelength. Following initial excitation to a higher electronic state, the molecule undergoes rapid non-radiative relaxation to the lowest vibrational level of the first excited singlet state. The eventual return to the ground state involves the emission of a photon.

6. (C) They are linearly proportional
The relationship between transmittance and absorbance is logarithmic rather than linear. Transmittance measures the fraction of incident light that passes through a sample, while absorbance represents the amount of light captured. Mathematically, absorbance is defined as the negative logarithm of transmittance. As the concentration of an analyte increases, transmittance decreases exponentially, resulting in a corresponding linear increase in the calculated absorbance values.

7. (D) To isolate a specific wavelength of light
A monochromator is an essential optical component designed to isolate a narrow band of wavelengths from a broad-spectrum light source. By using dispersive elements such as prisms or diffraction gratings, it spatially separates different colors of light. This allows the instrument to select a specific, nearly monochromatic wavelength to pass through the sample, ensuring accuracy and sensitivity during spectroscopic analysis.

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8. (A) Both A and R are true and R is the correct explanation of A.
Deviations from linearity in the Beer-Lambert law occur frequently when analyte concentrations exceed approximately ten millimolar. At these higher levels, the average distance between individual molecules decreases significantly, leading to electrostatic interactions that alter their charge distribution. Additionally, high solute concentrations change the refractive index of the solution, which affects the molar absorptivity and the resulting measured absorbance values.

9. (B) Gamma rays
Gamma rays occupy the extreme end of the electromagnetic spectrum, characterized by the

science, this range is optimal for most biological ultrastructural studies.

28. (C) Projection lens
A scanning electron microscope creates an image by scanning a focused electron beam over the sample surface and detecting emitted signals. Unlike a transmission electron microscope, which uses a projection lens to magnify and project the final image onto a screen or detector, the scanning system relies on electronic processing. It includes an electron gun, electromagnetic lenses, and a vacuum system.

29. (D) Overtone and combination vibrational bands
Near-infrared spectroscopy involves the absorption of radiation in the wavelength range between seven hundred and twenty-five hundred nanometers. This technique specifically detects molecular vibrations that correspond to overtones and combination bands of fundamental vibrations, particularly those involving hydrogen atoms. Consequently, it is highly sensitive to carbon-hydrogen, nitrogen-hydrogen, and oxygen-hydrogen bonds, making it valuable for the quantitative analysis of biological materials.

30. (A) I, IV and V
Raman spectroscopy is based on the inelastic scattering of monochromatic light, which occurs when incident photons interact with molecular vibrations. A molecular mode is Raman active only if it results in a change in the polarizability of the molecule. This technique provides a unique structural fingerprint and is particularly useful for biological samples because water exhibits only very weak Raman scattering.

31. (B) Michelson
Fourier Transform Infrared spectrometers utilize a Michelson interferometer to collect spectral data. This device splits an infrared beam into two paths, reflects them using mirrors, and recombines them to create an interference pattern called an interferogram. By measuring all wavelengths simultaneously and applying a Fourier transform, the instrument produces a complete infrared spectrum with high speed, sensitivity, and wavelength accuracy.

32. (D) Photomultiplier tube
A photomultiplier tube is an extremely sensitive light detector that utilizes the photoelectric effect to convert incident photons into an electrical current. When light strikes the photocathode, electrons are emitted and then accelerated through a series of dynodes. Each dynode collision causes the emission of multiple secondary electrons, resulting in a large current amplification that allows for the detection of very low-intensity light.

33. (A) Tryptophan and Tyrosine
The quantification of protein concentration at two hundred eighty nanometers is a standard biochemical technique. This specific ultraviolet absorbance is primarily due to the presence of aromatic amino acids, particularly tryptophan and tyrosine. These molecules contain conjugated ring systems that undergo electronic transitions when they absorb light at this wavelength. The total absorbance is directly proportional to the concentration of these amino acids.

34. (C) IR spectroscopy
Infrared spectroscopy is a fundamental analytical technique that measures the interaction of infrared radiation with molecular matter. When a molecule absorbs specific infrared wavelengths, the energy is used to induce transitions between molecular vibrational and rotational energy levels. By identifying the specific frequencies of light absorbed, researchers can determine the functional groups and structural features present within a chemical or biological compound.

35. (A) Change in polarizability
Raman spectroscopy and infrared spectroscopy provide complementary information about molecular vibrations. The fundamental difference lies in their selection rules; Raman spectroscopy requires a change in the molecular polarizability during vibration, whereas infrared spectroscopy requires a change in the permanent dipole moment. Consequently, symmetrical vibrations that are inactive in the infrared spectrum are often highly visible and intense in Raman scattering.

36. (D) Complete symmetry with no change in dipole during vibration
A molecule is considered infrared inactive if its vibrations do not produce a change in its permanent dipole moment. Complete structural symmetry, such as that found in homonuclear diatomic molecules like nitrogen or oxygen, prevents the absorption of infrared radiation. Because the interaction with infrared light

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depends on oscillating electric dipoles, these perfectly symmetrical vibrations remain completely invisible to standard infrared spectroscopic measurements.

37. (B) Decrease in transmitted light intensity
Turbidometry is an analytical technique used to measure the concentration of suspended particles in a liquid medium. It quantifies the decrease in the intensity of incident light as it passes directly through the sample. This reduction is caused by the scattering and absorption of light by the particles. The measured turbidity is related to the concentration and size of the suspended matter.

38. (C) It measures off-axis scattered light versus straight-line transmission
Nephelometry and turbidometry both measure light scattering by suspended particles, but they differ in their optical arrangement. Turbidometry measures the reduction in light intensity transmitted in a straight line through the sample. In contrast, nephelometry measures the intensity of light scattered at a specific angle, typically ninety degrees, relative to the incident beam. Nephelometry is generally more sensitive for low concentrations.

39. (D) To atomize the sample into ground-state free atoms
In atomic absorption spectrophotometry, the flame serves as an atomization source. Its primary function is to provide the thermal energy necessary to desolvate, volatilize, and dissociate the liquid sample into individual ground-state free atoms. These neutral atoms are then capable of absorbing light at discrete, characteristic wavelengths emitted by a hollow cathode lamp, allowing for the precise quantification of specific metallic elements.

40. (C) A is true but R is false.
Hollow cathode lamps are the standard light source used in atomic absorption spectrophotometry to provide narrow emission lines characteristic of a specific element. These lamps do not emit a continuous spectrum; instead, they produce light at discrete wavelengths that match the absorption profile of the analyte atoms. This high specificity ensures that the instrument can accurately measure a single element without interference.

41. (B) Chemical interference
Chemical interference in atomic absorption spectrophotometry occurs when the analyte reacts with other species in the sample to form thermally stable compounds. These complexes do not dissociate completely at the flame temperature, reducing the number of free atoms available for light absorption. This results in a decreased signal and inaccurate concentration measurements unless specific releasing agents are added to the sample solution.

42. (B) Adding a releasing agent like lanthanum
Chemical interferences in atomic absorption spectrophotometry are often managed by adding a releasing agent to the sample. For example, lanthanum is frequently used when analyzing calcium in the presence of phosphate ions. Lanthanum reacts more strongly with phosphate than calcium does, preventing the formation of refractory calcium-phosphate complexes. This ensures that calcium atoms are fully liberated in the flame for absorption.

43. (A) Emission is measured against a near-zero dark background.
Fluorimetry is inherently more sensitive than standard ultraviolet-visible spectrophotometry because it measures the emitted light signal against a near-zero background. In absorbance measurements, the instrument must distinguish a small difference between two large light intensities. In contrast, fluorescence detectors capture a positive signal from the sample against a dark background, allowing for the detection of extremely low concentrations of analytes.

44. (C) The difference in wavelength between the excitation and emission maxima
The Stokes shift is defined as the difference in wavelength or frequency between the maxima of the absorption and emission spectra of the same electronic transition. When a molecule absorbs a photon, it reaches an excited state and then rapidly loses some energy through non-radiative vibrational relaxation before emitting a photon. Consequently, the emitted light always has less energy and a longer wavelength.

45. (D) Argon
Inductively coupled plasma techniques utilize argon gas to generate and maintain a high-temperature plasma. Argon is preferred because it is chemically inert, preventing unwanted

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reactions with the sample, and has a relatively high ionization energy, which allows it to sustain a stable plasma through inductive heating. The resulting plasma reaches temperatures sufficient to atomize and ionize almost all elements for analytical detection.

46. (C) It provides lower detection limits and isotopic analysis capability
Inductively coupled plasma mass spectrometry offers several significant advantages over optical emission spectroscopy. It provides much lower detection limits, often in the parts per trillion range, and allows for the precise measurement of different isotopes of the same element. While both techniques use argon plasma for atomization, the mass spectrometer detector provides greater sensitivity and the ability to identify unknown elemental species.

47. (B) To absorb laser energy and facilitate desorption/ionization of the analyte
In matrix-assisted laser desorption/ionization, the matrix is a small organic molecule that is mixed with the analyte and crystallized on a target plate. Its primary roles are to absorb the energy from the laser pulse and facilitate the gentle desorption and ionization of large biomolecules without significant fragmentation. This allows for the mass spectroscopic analysis of intact proteins and nucleic acids.

48. (C) A is true but R is false.
Nuclear magnetic resonance spectroscopy is a powerful tool for determining the three-dimensional structures of proteins and other macromolecules in their native solution state. The signals are generated by the transitions of atomic nuclei between different energy levels when placed in a strong magnetic field and excited by radiofrequency waves. These transitions depend on the nuclear spin properties rather than electronic energy levels.

49. (A) Parts per million (ppm)
Chemical shift in nuclear magnetic resonance spectroscopy is a dimensionless value that represents the resonant frequency of a nucleus relative to a standard reference compound. It is universally expressed in units of parts per million. This convention makes the measured chemical shift independent of the external magnetic field strength of the spectrometer, allowing for the direct comparison of data across different instruments.

50. (A) P-2, Q-1, R-4, S-3
Various analytical techniques serve specific functions in biochemistry and environmental science. Inductively coupled plasma atomic emission spectroscopy is ideal for trace metal analysis in soil. Matrix-assisted laser desorption/ionization time-of-flight mass spectrometry is used for determining protein mass. Nuclear magnetic resonance is essential for metabolite structure elucidation, while atomic absorption spectrophotometry is utilized for the precise quantification of single metallic elements in water samples.

51. (A) ^{12}C
Nuclear magnetic resonance requires nuclei to have a non-zero net nuclear spin to be detectable. Carbon-twelve is considered NMR silent because it possesses an even number of both protons and neutrons, resulting in a net spin of zero. In contrast, isotopes like carbon-thirteen, hydrogen-one, and phosphorus-thirty-one have odd mass numbers or atomic numbers, giving them the necessary magnetic properties for spectroscopy.

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52. (D) Orbitrap
The Orbitrap mass analyzer is renowned for providing exceptionally high mass resolution and accuracy compared to quadrupoles or time-of-flight systems. It operates by trapping ions in an electrostatic field where they oscillate around a central electrode. The frequency of these oscillations is directly related to the mass-to-charge ratio. This advanced technology enables the identification of complex molecules with extremely small mass differences.

53. (B) First-order
The kinetic equation describing radioactive decay states that the rate of disintegration is directly proportional to the number of radioactive nuclei present. This mathematical relationship is identical to that of a first-order chemical reaction. Consequently, the time required for half of the radioactive atoms to decay, known as the half-life, remains constant regardless of the initial amount of material present in the sample.

54. (C) ^{3}H
Tritium is a radioactive isotope of hydrogen that emits low-energy beta particles during its decay

process. It possesses a half-life of approximately twelve point three years, making it a valuable tool for long-term labeling experiments in biological research. Because its beta emissions have very short range, tritium is commonly detected using liquid scintillation counting and requires minimal shielding compared to higher-energy emitters.

55. (D) Conversion of decay energy into light pulses via a fluor
Liquid scintillation counting is a highly sensitive technique used to measure radioactive decay, particularly from beta-emitting isotopes. The radioactive sample is dissolved in a specialized cocktail containing a primary fluor or scintillator. When a decay event occurs, the energy is transferred to the fluor, which then emits a pulse of light. These light flashes are detected and counted by photomultiplier tubes.

56. (A) ^{35}S
Sulfur-thirty-five is the most appropriate radioisotope for pulse-chase labeling of newly synthesized proteins because it is a key component of the amino acids methionine and cysteine. By introducing labeled sulfur during a short pulse, researchers can follow the synthesis, folding, and degradation of specific proteins over time. This isotope emits medium-energy beta particles that are easily detected using autoradiography or scintillation counting.

57. (B) A reduction in the efficiency of light output detection
Quenching in liquid scintillation counting refers to any process that reduces the efficiency of light production or detection during the counting process. It can be caused by chemical impurities that interfere with energy transfer or colored substances that absorb the emitted light before it reaches the detector. This results in a lower recorded count rate and shifts the pulse height spectrum toward lower energies.

58. (B) $\frac{1}{8}$

The amount of a radioactive isotope remaining after a given period follows an exponential decay pattern. After each half-life, exactly fifty percent of the previous amount of radioactivity remains. Therefore, after three half-lives, the fraction remaining is calculated by multiplying one-half by itself three times. This results in one-eighth of the original radioactive material, which corresponds to twelve point five percent.

59. (A) ^{32}P
Phosphorus-thirty-two is a high-energy beta emitter widely used for labeling nucleic acids in molecular biology. Due to the high energy of its emitted particles, it can penetrate several millimeters of tissue or plastic, necessitating the use of thick acrylic or Plexiglas shielding for safety. This isotope is particularly useful for Southern blotting, DNA sequencing, and other techniques requiring sensitive detection of phosphorus.

60. (A) P-2, Q-1, R-4, S-3
Radioisotopes are characterized by their specific half-lives, which determine their suitability for various biological applications. Phosphorus-thirty-two has a relatively short half-life of fourteen point three days. Sulfur-thirty-five decays over approximately eighty-seven days. Tritium possesses a longer half-life of twelve point three years, while carbon-fourteen is extremely stable, with a half-life of five thousand seven hundred thirty years, making it ideal for carbon dating.

61. (D) Silver bromide
In autoradiography, a radioactive specimen is placed in direct contact with a photographic emulsion containing silver bromide crystals. When ionizing radiation, such as beta particles, strikes these crystals, they undergo a chemical change that creates a latent image. This invisible image consists of small clusters of metallic silver. Upon subsequent development, these clusters are reduced to visible black grains that indicate radioactive locations.

62. (C) Developing
The processing of an autoradiogram follows a specific sequence of chemical steps similar to traditional photography. Immediately after the exposure period, during which the radioactive sample interacts with the film, the emulsion must be developed. The developer solution converts the latent image into visible silver grains. This step is followed by fixing to remove unexposed silver bromide and thorough washing to ensure stability.

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63. (B) ^{14}C
Melvin Calvin utilized the radioactive isotope carbon-fourteen to elucidate the complex biochemical pathways of carbon fixation during photosynthesis. By exposing algae to labeled carbon dioxide for varying durations and using paper chromatography to separate the resulting metabolites, he successfully traced the path of carbon atoms. This work led to the discovery of the Calvin cycle, identifying three-phosphoglycerate as the first stable product.

64. (D) To convert emission energy into light for enhanced detection
Intensifying screens are used in autoradiography to enhance the detection of high-energy radiation, such as gamma rays or energetic beta particles. The screen contains a phosphor material that absorbs the ionizing radiation and emits multiple photons of visible light in response. This conversion effectively amplifies the signal reaching the photographic film, significantly reducing the exposure time required to produce a clear image.

65. (A) The thickness of the emulsion and energy of the isotope
The spatial resolution of an autoradiograph defines the ability to precisely localize radioactive sources within a sample. This resolution is inversely proportional to both the thickness of the photographic emulsion and the energy of the emitted particles. Thicker emulsions and higher energy isotopes, like phosphorus-thirty-two, cause greater scattering of signals, resulting in blurred images and reduced detail compared to low-energy tritium.

66. (C) Washing and adding a large excess of unlabeled precursor
Pulse-chase experiments are designed to track the movement or metabolic fate of a specific molecule over time. The process begins with a short pulse, where cells are incubated with a radiolabeled precursor. This is followed by the chase period, where the labeled medium is replaced with a large excess of unlabeled precursor, allowing researchers to monitor the labeled molecules' progression.

67. (A) ^{125}I
Iodine-one hundred twenty-five is a versatile radioisotope commonly used in radioimmunoassays and protein labeling. It decays via electron capture, emitting low-energy Auger electrons and gamma radiation. Its relatively long half-life of sixty days and high specific activity make it ideal for sensitive detection in clinical assays. Because iodine can be easily incorporated into tyrosine residues, it is widely used for tracking hormones and antibodies.

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68. (D) A stationary phase and a mobile phase
Chromatography is a fundamental separation technique based on the differential distribution of components between two phases. The stationary phase remains fixed within a column or on a surface, while the mobile phase flows through it, carrying the analytes. Differences in the affinity of each analyte for these two phases result in varying migration speeds, leading to the effective separation of the mixture.

69. (B) Distance traveled by the analyte to distance traveled by the solvent front
The retention factor is a dimensionless value used in planar chromatography, such as paper or thin-layer chromatography, to characterize the migration of a substance. It is defined as the ratio of the distance traveled by the center of the analyte spot to the distance traveled by the mobile phase solvent front. Each compound has a characteristic value under specific experimental conditions.

70. (C) Non-polar compounds elute first, followed by polar compounds
In normal-phase chromatography, the stationary phase is polar, such as silica gel, while the mobile phase is non-polar. Consequently, non-polar compounds have less affinity for the stationary phase and move more quickly through the system. This results in a sequence where non-polar analytes elute first, followed by increasingly polar compounds that are more strongly retained by the polar stationary phase.

71. (D) The ratio of analyte concentration in the stationary phase to the mobile phase
The partition coefficient is a fundamental constant in chromatography that describes how an analyte distributes itself between the stationary and mobile phases at equilibrium. It is calculated as the ratio of the analyte concentration in the stationary phase to its concentration in the mobile phase. This value determines the retention time and the overall

efficiency of the separation for a particular compound.

72. (A) Selectivity, efficiency, and retention
The resolution between two chromatographic peaks indicates the degree of their separation. It is determined by three primary factors: selectivity, which relates to the chemical difference between analytes; efficiency, which describes the narrowness of the peaks; and retention, which measures how long the analytes remain on the column. Optimizing these parameters ensures that complex mixtures are resolved into distinct, quantifiable peaks.

73. (B) Partition
Paper chromatography primarily separates compounds based on the principle of partition between two liquid phases. The cellulose fibers of the paper adsorb a thin layer of water from the atmosphere, which acts as the stationary phase. As the organic mobile phase migrates up the paper, analytes partition between the bound water and the moving solvent according to their relative solubilities.

74. (B) Highly polar surface containing silanol groups
Silica gel is the most widely used stationary phase in thin-layer chromatography due to its highly polar nature. Its surface is covered with reactive silanol groups that interact with analytes through hydrogen bonding and dipole-dipole interactions. These polar sites preferentially retain polar molecules, while non-polar molecules move more rapidly with the mobile phase, facilitating effective separation based on differences in molecular polarity.

75. (A) To resolve complex mixtures that overlap in a single dimension
Two-dimensional thin-layer chromatography is a powerful technique used to improve the resolution of complex mixtures that cannot be fully separated in a single run. After the initial development, the plate is dried and rotated ninety degrees before being developed again with a different solvent system. This approach utilizes two distinct separation mechanisms, effectively spreading the components across the entire plate surface.

76. (C) Ninhydrin
Ninhydrin is a standard visualization reagent used in chromatography to detect amino acids, peptides, and proteins. When heated, it reacts with primary amines to produce a characteristic deep purple or blue-colored product known as Ruhemann's purple. This highly sensitive chemical reaction allows researchers to visualize the location of individual amino acids on thin-layer chromatography plates or paper chromatograms after the separation.

77. (D) Hydrostatic pressure (gravity)
In standard gravity-flow column chromatography, the movement of the mobile phase through the stationary phase bed is driven solely by hydrostatic pressure. The weight of the solvent column above the packing material provides the force necessary to overcome the resistance of the particles. This technique is commonly used for large-scale preparative separations where high pressure and rapid flow rates are unnecessary.

78. (C) Quaternary ammonium
Strong anion exchange chromatography utilizes a stationary phase containing positively charged functional groups that remain ionized across a wide pH range. The most common functional group for this purpose is quaternary ammonium. These groups attract and bind negatively charged anions from the sample. Separation occurs as anions with different charge densities or sizes are selectively eluted by increasing the salt concentration.

79. (B) Hydrodynamic volume
Size-exclusion chromatography, also known as gel filtration, separates molecules based on their hydrodynamic volume or size. The stationary phase consists of porous beads with specific pore sizes. Large molecules that cannot enter the pores elute first in the void volume, while smaller molecules penetrate the pores and take a longer path, eluting later. This method is ideal for desalting proteins.

80. (A) II, IV, III, I
An affinity chromatography protocol follows a logical sequence to ensure the specific capture and recovery of a target protein. The process begins with column equilibration to optimize binding conditions, followed by sample application. Next, a washing step removes non-specifically bound proteins. Finally, the target protein is eluted

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by changing the buffer conditions or adding a competitive ligand to disrupt the specific interaction.

81. (A) Helium or Nitrogen
Gas chromatography requires an inert carrier gas to serve as the mobile phase, transporting the vaporized sample through the column. Helium and nitrogen are the most commonly used gases because they do not react with the analytes or the stationary phase. The choice of carrier gas affects the separation efficiency and the sensitivity of various detectors used at the column outlet.

82. (C) Flame Ionization Detector (FID)
The flame ionization detector is the most widely used and nearly universal detector for organic compounds in gas chromatography. It works by burning the eluting analytes in a hydrogen-air flame, which produces ions from carbon-containing molecules. These ions generate an electrical current proportional to the mass of the carbon atoms passing through the flame, providing high sensitivity and a wide range.

83. (A) Increase mass transfer and column efficiency
High-performance liquid chromatography achieves superior separation by using very small, uniform packing particles. Reducing the particle size increases the surface area for interaction and shortens the distance analytes must diffuse within the mobile and stationary phases. This enhancement in mass transfer significantly improves column efficiency and resolution, although it necessitates the use of high pressure to maintain adequate flow.

84. (D) C18 (Octadecylsilane) modified silica
Reversed-phase high-performance liquid chromatography is the most common mode of separation in analytical chemistry. It utilizes a non-polar stationary phase, which is typically created by chemically bonding octadecylsilane or C18 chains to a silica support. In this system, polar analytes elute first, while non-polar molecules are more strongly retained through hydrophobic interactions, allowing for the effective separation of complex mixtures.

85. (B) Reversed-phase HPLC - Molecular shape and size
Different chromatographic techniques rely on specific physical or chemical properties for separation. Ion-exchange chromatography uses net charge, and affinity chromatography utilizes specific biological interactions. While gas-liquid chromatography depends on volatility and partition, reversed-phase high-performance liquid chromatography separates molecules based on their relative hydrophobicity. Assigning molecular shape and size to reversed-phase chromatography is incorrect, as those parameters characterize size-exclusion chromatography.

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86. (C) The mobile phase composition remains unchanged throughout the run
Isocratic elution in high-performance liquid chromatography refers to a separation where the composition of the mobile phase remains constant throughout the entire analysis. This approach is simple to perform and provides stable baseline conditions for detection. It is suitable for samples with relatively simple mixtures; however, for complex samples with widely varying retention times, gradient elution is often preferred to improve resolution.

87. (D) Refractive Index (RI) detector
The refractive index detector is a universal detector in high-performance liquid chromatography that measures the difference in refractive index between the pure mobile phase and the column eluent. While it is less sensitive than ultraviolet or fluorescence detectors, it can detect any analyte that differs in refractive index from the solvent. It is particularly useful for analyzing carbohydrates and other non-chromophoric compounds.

88. (A) The separation efficiency of the column
The theoretical plate number is a mathematical concept used to quantify the separation efficiency of a chromatographic column. It represents the number of discrete equilibrium stages that occur during the separation process. A higher plate number indicates a more efficient column capable of producing sharper peaks and better resolution. This value is influenced by the column length, particle size, and flow rate.

89. (B) Net charge
Electrophoretic mobility describes the velocity of a charged molecule in an electric field. It is directly proportional to the net electrical charge of the molecule and inversely proportional to the frictional coefficient, which depends on the molecule's size and shape. Therefore, a molecule

disturbed by the walls of the tube, resulting in sharp, distinct bands and easier recovery of the separated biological components after the run.

108. (C) Ambient light intensity
The sedimentation velocity of a particle in a centrifuge depends on the balance of centrifugal, buoyant, and frictional forces. Key factors include the particle's mass, size, and density, as well as the density and viscosity of the surrounding medium. While the applied centrifugal field strength is critical, environmental factors such as ambient light intensity have no physical influence on the sedimentation process.

109. (D) Vertical tube rotor
Vertical tube rotors provide the shortest possible path length for sedimentation because the tubes are oriented parallel to the axis of rotation. During centrifugation, particles only need to travel across the diameter of the tube rather than its entire length to reach the wall or bottom. This unique geometry allows for exceptionally fast pelleting times compared to fixed-angle or swinging-bucket rotors.

110. (B) II and III
Differential centrifugation is a fundamental technique for separating sub-cellular organelles based on their varying sedimentation rates. The process involves multiple steps where the supernatant is subjected to progressively higher centrifugation speeds to pellet increasingly smaller particles. Because the fractions are usually cross-contaminated, multiple washing steps are often required to achieve high purity, making single-step purification via this method essentially impossible.

111. (B) Buoyant density
Isopycnic centrifugation, also known as equilibrium density gradient centrifugation, separates particles strictly based on their buoyant density. The sample is placed in a gradient where the maximum density exceeds that of the particles. During prolonged centrifugation, each particle migrates to the specific region where its density matches that of the surrounding medium, regardless of the particle's size, shape, or initial position.

112. (C) I, III and IV
Density gradient centrifugation encompasses two distinct modes: rate-zonal and isopycnic. Rate-zonal centrifugation utilizes shallow gradients to separate particles by size and mass. Isopycnic centrifugation requires a steep gradient where particles reach an equilibrium based on buoyant density. Common materials include sucrose for separating organelles by size and cesium chloride for the density-based separation of nucleic acids, such as DNA.

113. (A) Nuclei
During the process of sub-cellular fractionation by differential centrifugation, the largest and densest components of the cell are the first to sediment. Nuclei have the highest mass and density among the major organelles, causing them to pellet at relatively low centrifugal forces, typically around six hundred times gravity. Subsequent steps at higher speeds are required to pellet smaller organelles like mitochondria.

114. (C) As a thin layer on top of a pre-formed gradient
In rate-zonal centrifugation, the sample must be carefully loaded as a very thin, concentrated layer on top of a pre-formed density gradient. This starting configuration is essential because the separation is based on the differential sedimentation velocities of the particles. A thin initial layer ensures that all particles of the same size and mass begin their journey from the same position.

115. (A) A high vacuum chamber
Ultracentrifuges reach extremely high rotational speeds, creating significant friction between the rotor and the air molecules in the chamber. This friction would quickly generate lethal amounts of heat, potentially damaging the samples and the instrument. To prevent this, ultracentrifuges are equipped with a high vacuum system that removes most of the air, allowing the rotor to spin with minimal resistance.

116. (D) Percoll or Ficoll
Separating intact, living cells requires a gradient medium that provides high density without creating excessive osmotic pressure. Percoll and Ficoll are colloidal silica or polymer-based materials designed specifically for this purpose. Unlike sucrose or cesium chloride, which can cause cells to shrink or lyse due to high osmolarity, these materials maintain a nearly physiological environment, ensuring high cell viability.

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migrate more slowly through the gel matrix. this continuous reorientation allows for the effective resolution of large genomic DNA that would otherwise co-migrate.

99. (A) Double immunodiffusion
Immunoelectrophoresis is a specialized technique that combines the principles of electrophoresis and double immunodiffusion. Initially, a mixture of antigens is separated in an agarose gel based on their charge and size. Following electrophoresis, an antiserum containing specific antibodies is placed in a parallel trough. As the antigens and antibodies diffuse toward each other, they form characteristic precipitin arcs at the equivalence zone.

100. (A) P-3, Q-4, R-1, S-2
Different electrophoretic techniques are specialized for various biological targets. Sodium dodecyl sulfate-polyacrylamide gel electrophoresis is used to determine denatured protein mass. Isoelectric focusing separates proteins according to their unique isoelectric points. Pulsed-field gel electrophoresis is necessary for resolving whole bacterial chromosomes, while standard agarose gel electrophoresis is the routine method for separating and analyzing plasmid DNA or other small fragments.

101. (B) Carrier ampholytes
Carrier ampholytes are essential mixtures of synthetic polyaminopolycarboxylic acids used to establish a stable and continuous pH gradient in isoelectric focusing. When an electric field is applied, these molecules migrate to their respective isoelectric points, creating a smooth gradient from anode to cathode. This gradient allows proteins to be separated with extreme precision based on their individual, characteristic isoelectric point values.

102. (C) First dimension separates by pI (IEF), second by mass (SDS-PAGE)
Two-dimensional gel electrophoresis is a high-resolution separation method that combines two different physical properties to resolve complex protein mixtures. In the first dimension, proteins are separated by their isoelectric point using isoelectric focusing. In the second dimension, the focused proteins are separated perpendicularly by their molecular weight using SDS-PAGE. This dual-separation approach can resolve thousands of individual protein spots.

103. (D) Antigen and antibody reach zone of equivalence
Precipitin arcs in immunoelectrophoresis occur at the precise location where diffusing antigens and antibodies reach the zone of equivalence. In this region, the concentrations of both components are optimal for the formation of large, insoluble immune complexes that precipitate out of the gel. These arcs are highly specific and provide information about the purity, concentration, and identity of the proteins present.

104. (A) Rotor radius and rotational speed (RPM)
Relative centrifugal force represents the amount of acceleration applied to a sample during centrifugation. It is calculated using two primary physical parameters: the rotational speed of the centrifuge, measured in revolutions per minute, and the radius of the rotor, measured from the axis of rotation to the sample. This standardized value allows for the accurate comparison of centrifugation protocols across different instruments.

105. (A) $10^{\{-13\}}$ seconds
The Svedberg unit is a non-SI unit used to express the sedimentation coefficient of biological macromolecules and organelles. It is defined as a unit of time equal to exactly ten to the power of negative thirteen seconds. This value describes the rate at which a particle sediments in a centrifugal field, which depends on its mass, density, and three-dimensional shape.

106. (B) A graphical tool to interconvert RPM, RCF, and rotor radius
A nomogram is a convenient graphical tool used by researchers to quickly interconvert between rotational speed in revolutions per minute, relative centrifugal force, and the radius of the centrifuge rotor. By aligning a straight edge across known values on the scaled axes, the user can determine the corresponding third parameter without performing complex manual calculations, ensuring accuracy in protocol standardization.

107. (A) Density gradient centrifugation
Swinging-bucket rotors are particularly well-suited for density gradient centrifugation. During operation, the buckets swing out horizontally, ensuring that the centrifugal force is always directed toward the bottom of the tube. This prevents the sample and gradient from being

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with a higher net charge will migrate more rapidly toward the electrode of opposite polarity during the electrophoresis.

90. (A) Both A and R are true and R is the correct explanation of A.
In sodium dodecyl sulfate-polyacrylamide gel electrophoresis, proteins are separated according to their molecular weight. The anionic detergent sodium dodecyl sulfate binds to proteins in a fixed ratio, denaturing them into linear chains and imparting a uniform negative charge. This process masks the intrinsic charge of the proteins, ensuring that they migrate toward the anode with a constant charge-to-mass ratio through the sieve.

91. (A) It intercalates between DNA base pairs and fluoresces under UV light.
Ethidium bromide is a fluorescent dye commonly used in agarose gel electrophoresis to visualize nucleic acids. It functions by intercalating between the stacked base pairs of double-stranded DNA. When the gel is exposed to ultraviolet light, the bound dye fluoresces brightly, allowing researchers to see the position and intensity of DNA bands. This sensitivity makes it a standard tool for genomic analysis.

92. (C) Concentrate protein samples into a sharp band before separation
The stacking gel is a critical component of the discontinuous buffer system used in sodium dodecyl sulfate-polyacrylamide gel electrophoresis. It possesses a lower polyacrylamide concentration and a different pH compared to the resolving gel. These conditions cause protein samples to accumulate or "stack" into extremely thin, concentrated bands at the interface of the two gels, significantly improving the final resolution.

93. (D) A combination of charge, mass, and 3D conformation
Native gel electrophoresis separates proteins in their folded, biologically active states without the use of denaturing agents. Unlike SDS-PAGE, where migration depends solely on molecular weight, native electrophoresis relies on a combination of the protein's intrinsic net charge, total mass, and three-dimensional conformation. This technique is valuable for studying protein-protein interactions, enzyme activity, and the quaternary structure of multi-subunit complexes.

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94. (C) To reduce disulfide bonds
Beta-mercaptoethanol and dithiothreitol are reducing agents used during the preparation of protein samples for denaturing electrophoresis. Their primary function is to break covalent disulfide bonds between cysteine residues, ensuring that multi-subunit proteins are dissociated and that individual polypeptide chains are completely unfolded. This step is essential for the accurate estimation of molecular weight based on the migration of linear protein chains.

95. (B) Isoelectric point (pI)
Isoelectric focusing is a high-resolution electrophoretic technique that separates proteins strictly on the basis of their isoelectric points. The process occurs within a stable pH gradient created by carrier ampholytes. Each protein migrates through the gradient until it reaches the specific pH where its net electrical charge is zero. This technique can distinguish between proteins with very small differences in pI.

96. (D) Zero
During isoelectric focusing, proteins migrate in an electric field through a pH gradient. As a protein moves, its net charge changes according to the surrounding pH. The migration continues until the protein reaches the region where the pH is equal to its isoelectric point. At this specific point, the protein has a net charge of zero and ceases to move.

97. (A) Inability to resolve very large DNA fragments ($>$50 kb)
Pulsed-field gel electrophoresis was specifically developed to resolve very large DNA molecules, such as whole chromosomes, which cannot be separated by standard agarose gel electrophoresis. In conventional systems, DNA fragments larger than approximately fifty kilobases migrate at the same rate regardless of size. By periodically changing the direction of the electric field, pulsed-field systems force large molecules to reorient.

98. (C) By periodically alternating the direction of the electric field
Pulsed-field gel electrophoresis achieves the separation of megabase-sized DNA molecules by periodically alternating the direction of the electric field. Because larger DNA fragments take longer to reorient themselves to the new field direction compared to smaller fragments, they

117. (B) Continuously monitors sedimentation in real-time via optical systems
Analytical ultracentrifugation is a specialized technique used to study the physical properties of macromolecules in solution. Unlike preparative methods used for bulk separation, analytical systems are equipped with sophisticated optical sensors that monitor the sedimentation process in real-time. This allows for the precise determination of molecular weights, sedimentation coefficients, and the degree of molecular heterogeneity or association within a sample.

118. (C) The capacity of a plant cell to regenerate a fertile plant
Cellular totipotency is a fundamental concept in plant biology and tissue culture. It refers to the remarkable ability of a single, differentiated plant cell to undergo dedifferentiation and subsequently regenerate into a complete, fertile plant. This unique genetic potential allows for the clonal propagation of elite varieties, the rescue of endangered species, and the successful regeneration of genetically modified plants from cells.

119. (D) Sucrose
In vitro plant tissue culture systems are not photoautotrophic and require an exogenous supply of energy. Sucrose is the most common carbon and energy source added to culture media. It provides the necessary carbohydrates for cellular metabolism, growth, and development. Additionally, sucrose contributes to the osmotic potential of the medium, which is critical for maintaining proper cell turgor and health.

120. (A) I, II and III
Plant growth regulators are critical for controlling the development of tissues in vitro. The ratio of auxin to cytokinin determines the type of organogenesis observed. A high auxin concentration promotes the formation of roots, while a high cytokinin concentration encourages shoot development. When both hormones are present in roughly equal amounts, the cells tend to proliferate as an unorganized mass called callus.

121. (B) Agar
Agar is the universal gelling agent used to solidify plant tissue culture media. Extracted from red algae, it is preferred because it remains solid at the temperatures used for incubation and is not degraded by plant enzymes. Agar provides a stable support for the explants while allowing for the diffusion of nutrients and water from the medium to the growing tissues.

122. (B) Sodium hypochlorite
Success in tissue culture depends on maintaining a completely sterile environment. Before being placed in the culture medium, plant explants must undergo surface sterilization to remove potentially contaminating bacteria and fungi. Sodium hypochlorite, the active ingredient in household bleach, is widely used for this purpose. It effectively kills surface microorganisms without being excessively toxic to the internal plant tissues if used correctly.

123. (A) Haploid or double-haploid homozygous lines
Anther and microspore culture are powerful biotechnological techniques used to regenerate plants from male gametic cells. Because these cells are haploid, the resulting plants are also haploid. Through subsequent chromosome doubling, researchers can rapidly produce double-haploid plants that are completely homozygous. This process significantly accelerates plant breeding programs by eliminating the need for multiple generations of self-pollination to achieve genetic stability.

124. (A) I, II and III
Plant tissue culture media, such as the Murashige and Skoog formulation, contain essential inorganic nutrients categorized by the amounts required. Macronutrients are needed in relatively large quantities and include nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur. In contrast, micronutrients like iron, zinc, manganese, and boron are required in only trace amounts but are equally vital for various enzymatic and physiological processes.

125. (D) Meristem culture
Meristem culture is a specialized technique used to eliminate viruses and other systemic pathogens from infected plant varieties. The shoot apical meristem is generally free of viruses because of its rapid cell division and the absence of vascular connections. By carefully excising and culturing the tiny meristematic dome, researchers can regenerate whole plants that are certified free of the original viral infections.

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the data points cluster around a straight line. The sign of the coefficient indicates whether the relationship is positive or negative, while the absolute value represents the strength. It is important to remember that correlation does not imply a causal relationship.

199. (C) -1 to +1
The correlation coefficient is a standardized value that always falls within a fixed range from negative one to positive one. A value of positive one indicates a perfect positive linear relationship, while negative one represents a perfect negative linear relationship. A value of zero suggests that there is no linear association between the variables. Values outside this range are mathematically impossible in standard correlation analysis.

200. (C) I only
Interpreting correlation coefficients requires caution. A high value, such as point nine zero, clearly indicates a very strong linear relationship between two variables. However, a correlation of zero only means that no linear relationship exists; a strong non-linear relationship might still be present. Most importantly, correlation never proves causation, as the observed association could be driven by a third, unmeasured lurking variable.

201. (B) 0.64
The coefficient of determination is calculated by squaring the Pearson correlation coefficient. If the correlation between two variables is point eight zero, then point eight zero squared equals point six four. This value is often converted to a percentage to describe the proportion of the total variation that is shared between the two variables, which in this case would be sixty-four percent.

202. (B) The proportion of variance in the dependent variable predictable from the independent variable
The coefficient of determination, denoted as R-squared, is a fundamental statistic in regression analysis. It represents the proportion of the total variance in the dependent variable that can be explained or predicted by the independent variable in the model. An R-squared of point seven five means that seventy-five percent of the variability in the outcome is accounted for by the predictor variable.

203. (A) The slope of the regression line
In a simple linear regression equation, the coefficient attached to the independent variable represents the slope of the best-fit line. The slope indicates the average change in the dependent variable for every one-unit increase in the independent variable. A positive slope means both variables increase together, while a negative slope means the dependent variable decreases as the independent variable increases.

204. (C) Residuals (vertical distances from points to the line)
The method of least squares is the standard procedure for finding the best-fitting line through a set of data points. It works by minimizing the sum of the squares of the vertical distances between each observed data point and the regression line. These distances are called residuals. By minimizing these errors, the resulting line provides the most accurate possible linear model for the dataset.

205. (D) As X increases, Y decreases proportionally.
A negative linear correlation occurs when two variables move in opposite directions. This means that as the value of the independent variable X increases, the value of the dependent variable Y tends to decrease. On a scatterplot, these data points would form a downward-sloping pattern. Common examples include the relationship between the price of a good and the quantity demanded by consumers.

206. (C) Establishes a predictive functional relationship mapping an independent variable to a dependent variable
While correlation and regression are related, they serve different analytical purposes. Correlation simply measures the degree of association between two variables without assuming any directionality. Regression analysis goes further by establishing a functional, predictive relationship. It identifies one variable as the independent predictor and the other as the dependent outcome, allowing researchers to estimate the value of one based on the other.

207. (B) The dependent variable Y does not change linearly as a function of X
A regression slope of zero indicates that there is no linear relationship between the independent and dependent variables. It means that as the independent variable changes, the predicted

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135. (D) Rapid, in a $37^{\circ}C$ water bath
For successful recovery of cryopreserved cells, the thawing process must be carried out as rapidly as possible. This is usually done by immersing the vials in a thirty-seven degree Celsius water bath. Rapid warming prevents the recrystallization of small, harmless ice crystals into larger, lethal ones as the temperature rises. After thawing, the cryoprotectants must be carefully diluted to avoid osmotic shock.

136. (A) Both A and R are true and R is the correct explanation of A.
Vitrification requires significantly higher concentrations of cryoprotectants compared to traditional slow-freezing methods. These solutes work by increasing the viscosity of the liquid to such an extent that the water molecules cannot reorganize into an ice lattice during rapid cooling. Instead, the solution solidifies into a transparent, glass-like state. This process effectively eliminates mechanical damage from ice, provided that the cooling is fast.

137. (B) Mature fleshy fruit tissues
Tissues with high water content and complex, large-cell structures are often the most difficult to cryopreserve successfully. Mature fleshy fruit tissues are particularly recalcitrant because their large vacuoles contain significant amounts of water, which is prone to lethal ice formation. In contrast, small, dense structures like pollen grains or apical meristems have less water and more concentrated cytoplasm, making them better candidates for freezing.

138. (A) Rapidly alternate block temperatures to facilitate denaturation, annealing, and extension
A thermal cycler is the core piece of equipment for the polymerase chain reaction. Its primary function is to provide precise and rapid temperature changes across multiple cycles. By alternating between high temperatures for DNA denaturation, lower temperatures for primer annealing, and intermediate temperatures for strand extension, the instrument enables the exponential amplification of specific DNA sequences from a complex template.

139. (A) Double-stranded DNA template separates into single strands
The denaturation step is the first stage of each PCR cycle. By heating the reaction mixture to temperatures between ninety-four and ninety-six degrees Celsius, the hydrogen bonds between the complementary base pairs of the template DNA are broken. This results in the separation of double-stranded DNA into two single strands, providing the necessary access for primers and DNA polymerase in subsequent steps.

140. (C) A is true but R is false.
Taq DNA polymerase revolutionized biotechnology because of its exceptional thermal stability. It was originally isolated from the thermophilic bacterium Thermus aquaticus, which thrives in high-temperature hot springs, not in glaciers. This property allows the enzyme to remain functional even after multiple rounds of high-temperature denaturation, eliminating the need to add fresh enzyme after every cycle of the polymerase chain reaction.

141. (D) $3-5^{\circ}C$ below the lowest melting temperature (T_m) of the primers
The annealing temperature is a critical parameter for ensuring the specificity of a PCR reaction. It is typically set three to five degrees below the calculated melting temperature of the primers. This temperature must be low enough to allow the primers to bind stably to their complementary sequences on the template, yet high enough to prevent non-specific binding and the formation of undesirable products.

142. (C) Primer dimers and hairpin structures
Effective PCR primer design is essential for successful DNA amplification. One must avoid sequences that can fold back on themselves to form hairpins or bind to each other to create primer dimers. These secondary structures consume primers and reagents, significantly reducing the yield of the desired target sequence. Most design software tools specifically check for these interactions to ensure high reaction efficiency.

143. (B) $2^{\{30\}}$
The polymerase chain reaction is characterized by exponential amplification. In each cycle, the number of target DNA molecules theoretically doubles, as each new strand can serve as a template in the following round. Therefore, if the process begins with a single double-stranded DNA molecule, the number of molecules present after thirty cycles is represented by two raised to the power of thirty.

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126. (C) Cellulase and pectinase
Protoplasts are plant cells that have had their cell walls entirely removed. This is achieved by treating plant tissues with a cocktail of hydrolytic enzymes, primarily cellulase and pectinase. Cellulase breaks down the cellulose fibers, while pectinase degrades the middle lamella that holds the cells together. The resulting naked cells are spherical and highly fragile, requiring a specialized osmotic environment to prevent lysis.

127. (B) Somatic embryogenesis generates bipolar structures having both shoot and root axes.
Somatic embryogenesis is a developmental pathway where somatic cells form structures resembling zygotic embryos. Unlike organogenesis, which produces unipolar structures like either a shoot or a root, somatic embryos are bipolar, possessing both a shoot and a root apex simultaneously. Furthermore, somatic embryos have no direct vascular connection to the parent tissue, allowing them to be easily separated and used for artificial seeds.

128. (D) To halt metabolic processes for long-term cell viability
Cryopreservation is a specialized technique used to preserve biological materials, such as cells and tissues, at ultra-low temperatures, usually in liquid nitrogen. The fundamental goal is to halt all metabolic processes and chemical reactions, effectively putting the cells into a state of suspended animation. This allows for the long-term storage of genetic resources while maintaining the viability and genetic stability of the samples.

129. (A) Severe osmotic dehydration and solute toxicity
During slow-cooling cryopreservation, ice begins to form in the extracellular medium. This increases the concentration of solutes outside the cell, creating an osmotic gradient that draws water out of the cytoplasm. If the cooling is too slow, the cell becomes excessively dehydrated, leading to lethal concentrations of internal solutes and irreversible damage to the plasma membrane and sensitive cellular proteins.

130. (A) I, II, III and IV
Cryoprotectants are essential chemicals added to the freezing medium to protect cells during the cooling and thawing processes. They function by lowering the freezing point and increasing the viscosity of the solution. Penetrating agents like DMSO enter the cell to stabilize internal structures, while non-penetrating agents like sucrose provide external osmotic protection. However, high concentrations of these agents can be toxic.

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131. (C) $-196^{\circ}C$
Liquid nitrogen is the standard refrigerant for biological cryopreservation due to its extremely low boiling point of approximately negative one hundred ninety-six degrees Celsius. At this ultra-low temperature, biological activity is completely arrested, preventing the degradation of DNA and proteins. Storing samples in the liquid phase ensures temperature stability, although many facilities use the vapor phase to reduce the risk of contamination.

132. (D) Transitioning water into an amorphous solid glass phase
Vitrification is a cryopreservation technique that avoids the formation of damaging ice crystals. It involves using extremely high concentrations of cryoprotectants and ultra-rapid cooling to transition the cellular water directly into an amorphous, solid glass-like state. Because the water does not form an ordered crystalline lattice, the physical structure of the cell is preserved without the mechanical damage caused by sharp ice.

133. (B) The cooling rate $(\frac{^{\circ}C}{\text{min}})$
The cooling rate is the most critical parameter in a two-step freezing protocol for cryopreservation. It must be slow enough to allow sufficient osmotic dehydration, which prevents internal ice formation, yet fast enough to avoid the toxic effects of concentrated solutes. Optimization of this rate is essential for maximizing the post-thaw recovery of viable cells and ensuring the stability of the samples.

134. (C) Dimethyl sulfoxide (DMSO)
Dimethyl sulfoxide is the most widely used penetrating cryoprotectant in mammalian cell culture and many plant systems. Its small molecular size and amphiphilic nature allow it to rapidly cross the plasma membrane. Once inside, DMSO interacts with water molecules to prevent ice crystallization and stabilizes the phospholipid bilayer. It is typically used at concentrations between five and ten percent in the freezing medium.

153. (B) Varying repeat unit counts due to replication slippage
Simple sequence repeats are highly polymorphic due to the high rate of mutations that alter the number of repeat units at a locus. This variation is primarily caused by replication slippage, where the DNA polymerase "slips" during synthesis of the repetitive region, leading to insertions or deletions. This results in high allelic diversity among individuals, even within the same species or population.

154. (B) It has low reproducibility between different laboratories
Despite its simplicity and low cost, the random amplified polymorphic DNA technique has a major limitation: its low reproducibility. Because it uses short primers and low annealing temperatures, the resulting banding patterns are extremely sensitive to minor variations in reaction conditions, such as template quality, magnesium concentration, and thermal cycler performance. This makes it difficult to compare results between different laboratories or even separate experiments.

155. (A) A single base pair substitution at a specific locus
Single nucleotide polymorphisms are the most abundant type of genetic variation in most organisms. A SNP represents a variation at a single position in the DNA sequence where one nucleotide is replaced by another. These variations are highly stable and occur throughout the genome. Modern high-throughput sequencing and microarray technologies allow for the rapid detection of thousands of SNPs for genomic analysis.

156. (C) Marker-Assisted Selection (MAS)
Marker-assisted selection is a modern plant breeding technique that uses molecular markers to identify the presence of desirable genes or traits. Instead of waiting for plants to mature to observe physical traits, breeders can screen seedlings for markers that are closely linked to the target gene. This significantly speeds up the selection process, increases accuracy, and allows for the early elimination of undesirable plants.

157. (D) Amplifying a specific locus via PCR followed by restriction enzyme digestion
Cleaved amplified polymorphic sequences are molecular markers that combine the simplicity of PCR with the specificity of restriction enzymes. First, a specific genomic locus is amplified using targeted primers. The resulting PCR product is then digested with a specific restriction enzyme. Polymorphisms are detected as differences in the sizes of the resulting fragments, which are visualized by electrophoresis on an agarose gel.

158. (C) The 16S and 23S rRNA gene operons
Ribotyping is a powerful molecular typing technique used to identify and characterize bacterial strains. It focuses on variations within the highly conserved ribosomal RNA gene operons, particularly the sixteen-S and twenty-three-S regions. Because these regions are essential for protein synthesis and present in all bacteria, they serve as excellent targets for evolutionary studies and for identifying specific pathogens in clinical or environmental samples.

159. (B) It is strictly maternally inherited in most animals and lacks recombination
Mitochondrial DNA is a valuable tool for evolutionary and phylogenetic studies because of its unique inheritance pattern. In most animals, it is inherited strictly from the mother, meaning it does not undergo recombination like nuclear DNA. This allows researchers to trace maternal lineages directly through time. Additionally, mtDNA has a high mutation rate, which is useful for resolving relationships between closely related species.

160. (B) Restriction Digestion → Electrophoresis → Membrane Transfer → Hybridization
Southern blotting follows a precise sequence of steps to identify specific DNA sequences. The process begins with restriction digestion to cut the DNA into fragments. These are then separated by agarose gel electrophoresis. The separated fragments are transferred to a solid membrane, where they are permanently fixed. Finally, the membrane is incubated with a labeled probe during hybridization to detect the target sequence.

161. (A) Cytochrome c oxidase subunit I (COI)
DNA barcoding is a standardized method for identifying biological species using a short, specific DNA sequence. In animals, the universal target is a segment of the mitochondrial gene cytochrome c oxidase subunit one. This region provides enough sequence variation to distinguish between closely related species while remaining

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conserved within a species. This technique allows for rapid biodiversity assessment and species identification from minimal samples.

162. (C) Reconstruct the evolutionary relationships and common ancestry among taxa
Molecular phylogenetic analysis uses DNA or protein sequence data to reconstruct the evolutionary history of organisms. The primary goal is to determine the branching patterns of descent and identify common ancestors among different taxa. By comparing sequence similarities and differences, researchers can create phylogenetic trees that represent the most likely evolutionary relationships and help explain the origin and diversification of biological life.

163. (A) Maximum Likelihood
Maximum likelihood is a statistically sophisticated method for constructing phylogenetic trees. It evaluates the probability that a specific evolutionary model would produce the observed molecular sequence data. By testing various tree topologies and branch lengths, the algorithm identifies the tree that maximizes this probability. This method is highly robust and widely used, although it requires significant computational power for large datasets.

164. (D) A taxon known to be completely unrelated, serving to root the tree
In phylogenetics, an outgroup is a species or group that is known to have diverged before the common ancestor of the taxa being studied. Its primary purpose is to provide a reference point for rooting the phylogenetic tree. This allows researchers to determine the direction of evolutionary change and distinguish between ancestral and derived character states within the group of interest.

165. (B) Specific RNA molecules
Northern blotting is a core molecular biology technique used to detect and quantify specific RNA molecules within a sample. The process involves separating RNA fragments by size using denaturing gel electrophoresis, followed by their transfer to a solid membrane. The membrane is then probed with a complementary labeled nucleic acid sequence, allowing for the study of gene expression and transcript size.

166. (C) An enzyme-conjugated specific antibody
Western blotting, also known as immunoblotting, is used to detect specific proteins. After proteins are separated by electrophoresis and transferred to a membrane, the target protein is identified using a highly specific primary antibody. A secondary antibody, typically conjugated to an enzyme or a fluorophore, is then added to visualize the binding. this interaction provides information about the protein's presence, size, and abundance.

167. (D) Capillary action using highly absorbent paper towels
Standard Southern transfer utilizes capillary action to move DNA from the gel to the membrane. A stack of dry, absorbent paper towels is placed on top of the membrane, creating a suction force that draws buffer from a reservoir through the gel. As the buffer moves upward, it carries the DNA fragments with it, trapping them onto the surface of the membrane.

168. (A) Nitrocellulose or Nylon
Choosing the correct membrane is critical for successful blotting. Nitrocellulose is a traditional choice that offers high protein and DNA binding capacity but can be fragile. Nylon membranes are more physically durable and provide superior binding for small nucleic acid fragments, making them the preferred choice for many Northern and Southern blot applications. Both materials ensure that the transferred molecules remain immobilized during hybridization.

169. (B) To saturate non-specific binding sites on the membrane with a generic protein
The blocking step is essential in Western blotting to prevent the antibodies from binding non-specifically to the membrane surface. Membranes have a high affinity for all proteins; without blocking, the primary and secondary antibodies would stick everywhere, resulting in a dark background. By incubating the membrane with a solution of generic protein, such as non-fat dry milk or bovine serum albumin, these sites are saturated.

170. (A) I, II, IV, V, III
A Western blot follows a specific workflow to detect a target protein. Proteins are first separated by SDS-PAGE and then transferred to a solid membrane. The membrane is blocked and then incubated with a primary antibody followed

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by a secondary antibody. Finally, a substrate is added to generate a detectable signal, such as color or light, allowing the target protein to be visualized.

171. (A) Immobilized capture antibody, target antigen, enzyme-linked detection antibody
A sandwich ELISA is a highly specific assay format used to detect and quantify antigens. It requires two different antibodies that bind to different epitopes on the target molecule. The "capture" antibody is immobilized on the plate to trap the antigen from the sample. A second, enzyme-linked "detection" antibody then binds to the trapped antigen, forming a molecular sandwich that generates a signal.

172. (C) The specific target antigen
In an indirect ELISA, the microtiter plate is initially coated with a specific antigen. This format is primarily used to detect antibodies in patient serum, such as those produced in response to a viral infection. When the serum is added, any specific antibodies present will bind to the immobilized antigen. An enzyme-linked secondary antibody is then used to detect the bound primary antibodies.

173. (D) Nucleic acid hybridization
Microarray technology is a high-throughput method that allows for the simultaneous analysis of thousands of genes. Its fundamental principle is nucleic acid hybridization, where a labeled DNA or RNA sample is applied to a slide containing thousands of specific, immobilized probes. The sample molecules will only bind to probes with complementary sequences, allowing for the precise identification and quantification of the targets present.

174. (C) Cy3 (green) and Cy5 (red) fluorophores
Two-color DNA microarrays are used to compare gene expression between two different samples, such as a control and a treatment. The cDNA from each sample is labeled with a different fluorescent dye, usually Cy3 for green and Cy5 for red. Both labeled samples are hybridized to the same microarray slide. The relative ratio of red to green fluorescence at each spot indicates the differential expression of that gene.

175. (B) Microarrays rely on known probe sequences; RNA-Seq provides sequence data for all transcripts present.
While both microarrays and RNA-Seq measure gene expression, they differ in their fundamental approach. Microarrays require prior knowledge of the target sequences to design the probes on the slide. In contrast, RNA-Seq uses next-generation sequencing to directly determine the sequence of all RNA molecules in a sample. This allows for the discovery of novel transcripts, splice variants, and mutations that microarrays cannot detect.

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176. (D) Horseradish peroxidase (HRP)
Horseradish peroxidase is the most common enzyme conjugate used in ELISA and Western blot detection systems. When a suitable substrate, such as TMB or luminol, is added, HRP catalyzes a chemical reaction that produces a visible color change or emits light. This amplification step allows for the extremely sensitive detection of very low amounts of target molecules, making it a standard tool in diagnostics.

177. (A) High-throughput profiling of protein abundance in a sample
Protein microarrays are powerful tools for the large-scale analysis of protein expression and function. In an antibody microarray, hundreds of different specific antibodies are spotted onto a slide to capture their target proteins from a complex mixture. By measuring the amount of protein bound to each spot, researchers can profile the relative abundance of many proteins simultaneously, providing a comprehensive view of the proteome.

178. (C) The affinity constant of the specific antibody used
The sensitivity of any immunoassay, including ELISA, is fundamentally limited by the affinity of the antibody for its antigen. The affinity constant describes the strength of this interaction. High-affinity antibodies can bind their targets even at extremely low concentrations, resulting in a lower limit of detection. While instrumentation and protocol optimization are important, the biochemical quality of the antibody is the primary determinant of sensitivity.

179. (A) Arithmetic Mean
The arithmetic mean is the sum of all values in a dataset divided by the total number of observations. Because every individual value

contributes to the sum, the mean is highly sensitive to extreme outliers. A single exceptionally large or small value can significantly shift the mean away from the bulk of the data, potentially leading to misleading conclusions about the central tendency.

180. (D) The average degree of dispersion or spread around the mean
Standard deviation is a fundamental measure of dispersion in statistics. It quantifies the average amount by which individual data points differ from the arithmetic mean of the dataset. A low standard deviation indicates that the points tend to be very close to the mean, while a high standard deviation suggests that the data is spread out over a wider range of values.

181. (B) Variance is the square of standard deviation
Variance and standard deviation are both measures of data spread, and they are directly related mathematically. Variance is calculated by taking the average of the squared differences from the mean. Standard deviation is simply the positive square root of the variance. Because standard deviation is expressed in the same units as the original data, it is often preferred for descriptive reporting.

182. (C) SD measures dispersion in a sample; SE estimates the precision with which the sample mean estimates the population mean.
While they sound similar, standard deviation and standard error serve different purposes. Standard deviation describes the inherent variability within a single sample. In contrast, standard error measures the uncertainty of the sample mean as an estimate of the true population mean. It tells us how much the sample mean would likely vary if the experiment were repeated many times with different samples.

183. (B) $\frac{SD}{\sqrt{n}}$

The standard error of the mean is calculated by dividing the sample standard deviation by the square root of the number of observations. This formula demonstrates that the precision of the mean estimate increases as the sample size grows. Because the denominator includes the square root of the sample size, quadrupling the sample size will reduce the standard error by exactly half.

184. (C) 95%
In a perfectly normal, bell-shaped distribution, the data is distributed according to specific mathematical probabilities. Approximately sixty-eight percent of the observations fall within one standard deviation of the mean. This increases to approximately ninety-five percent within two standard deviations. Finally, about ninety-nine point seven percent of the data points are contained within three standard deviations, which defines the empirical rule of statistics.

185. (B) $\frac{SD}{Mean} \times 100$

The coefficient of variation is a standardized measure of relative dispersion, expressed as a percentage. It is calculated by dividing the standard deviation by the mean and multiplying the result by one hundred. This metric is particularly useful for comparing the variability of different datasets that have different units or widely different means, as it provides a unitless measure of precision.

186. (A) Both A and R are true and R is the correct explanation of A.
The standard error of the mean represents the variability of sample means. As the sample size increases, the standard error decreases, indicating that the sample mean becomes a more precise estimate of the population mean. This is because the sample size appears in the denominator of the standard error formula. Consequently, larger studies provide more reliable results and have higher statistical power.

187. (A) Coefficient of Variation
The coefficient of variation is the most appropriate statistic for comparing the relative variability of two different traits measured in different units. Because it is calculated as the ratio of the standard deviation to the mean, the units cancel out, resulting in a unitless percentage. This allows a researcher to determine whether plant height or grain yield shows greater relative spread within a population.

188. (B) $n-1$
Degrees of freedom represent the number of values in a final calculation that are free to vary. When calculating the variance or standard deviation of a sample, one degree of freedom is used to estimate the sample mean. Therefore, the degrees of freedom for the sum of squares is

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equal to the total number of observations minus one. This correction is essential for providing an unbiased estimate.

189. (D) Three or more sample means
Analysis of variance is a powerful statistical tool designed to determine if there are significant differences between the means of three or more independent groups. While a t-test can compare two means, ANOVA is needed for larger sets to avoid the increased risk of a Type I error. It works by comparing the variance between the groups to the variance within the groups.

190. (B) P-3, Q-2, R-1, S-4
An ANOVA table contains several key components that help interpret the results. The total sum of squares represents the overall variation in the data. The mean square is the sum of squares divided by the degrees of freedom, providing an estimate of variance. The F-ratio is the statistic used to test for differences, while the p-value indicates the probability of the results.

191. (C) Mean Square Between / Mean Square Within
The F-statistic in a one-way ANOVA is a ratio that compares two types of variance. The numerator is the mean square between groups, which represents the variation caused by the treatments. The denominator is the mean square within groups, which represents the random error variation. If the treatment effect is significant, the F-statistic will be much larger than one, leading to a small p-value.

192. (D) All group means are statistically equal.
Every statistical test begins with a null hypothesis. For a one-way ANOVA, the null hypothesis assumes that there is no real difference between the means of the various treatment groups being tested. It posits that any observed differences are merely due to random sampling variation. If the p-value is below the significance level, this null hypothesis is rejected in favor of the alternative.

193. (A) Reject the null hypothesis
In hypothesis testing, the p-value is compared to a pre-defined significance level, usually point zero five. A p-value of point zero one five is less than point zero five, which indicates that the observed results are unlikely to have occurred by chance alone. Therefore, the researcher rejects the null hypothesis and concludes that there is a statistically significant difference among the group means.

194. (C) A linear relationship between two variables
To ensure the validity of an ANOVA, several assumptions must be met. These include the independence of observations, the normal distribution of residuals, and the homogeneity of variances among the different groups. While linear regression assumes a linear relationship between two continuous variables, ANOVA does not have this requirement, as it focuses on comparing the means of different categorical treatment groups.

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195. (A) The random or unexplained inherent variability within the populations
Mean square error, or within-group mean square, is a critical value in the ANOVA table. It provides an estimate of the inherent, random variation that exists within the populations being sampled. This represents the noise or unexplained variability that is not caused by the treatments. The smaller this value is relative to the between-group variation, the more likely the treatments are to be significant.

196. (D) Post-hoc test (e.g., Tukey's HSD)
A significant ANOVA result only tells you that at least one pair of group means is different; it does not specify which ones. To identify the exact differences, researchers must perform a post-hoc test. Tukey's Honestly Significant Difference test is a common choice because it controls the family-wise error rate, allowing for multiple pairwise comparisons while maintaining the overall significance level of the experiment.

197. (B) Treatments, Blocks, and Error
The randomized complete block design is a common experimental structure used to control for known sources of variability. In this design, the total variation in the data is partitioned into three distinct components: variation due to the treatments, variation due to the blocks, and the remaining unexplained error variation. By removing the block effect from the error, the test becomes more sensitive and powerful.

198. (C) The strength and direction of the linear relationship between two continuous variables
The Pearson correlation coefficient is a measure used to describe the linear association between two continuous variables. It tells us how closely

144. (D) Binding specifically to double-stranded DNA and emitting fluorescence
SYBR Green is a widely used fluorescent dye in real-time quantitative PCR. It functions by binding specifically to the minor groove of all double-stranded DNA molecules in the reaction. When bound to DNA, its fluorescence intensity increases several hundred-fold. By measuring this signal at the end of each cycle, the instrument can monitor the accumulation of the PCR product in real-time.

145. (A) It functions as an essential cofactor for Taq DNA polymerase activity.
Magnesium ions are indispensable in the PCR reaction buffer. They act as a divalent cation cofactor for the DNA polymerase, facilitating the formation of the phosphodiester bond between nucleotides. Furthermore, magnesium ions stabilize the interaction between the primers and the template DNA. The concentration of magnesium must be carefully optimized, as too little prevents amplification while too much promotes non-specific products.

146. (C) Pfu polymerase
Pfu DNA polymerase is isolated from the hyperthermophilic archaeon Pyrococcus furiosus. Unlike the standard Taq polymerase, Pfu possesses a strong three-prime to five-prime exonuclease activity, which allows it to correct misincorporated nucleotides during synthesis. This proofreading capability results in a significantly lower error rate, making it the preferred enzyme for applications requiring high sequence fidelity, such as gene cloning and sequencing.

147. (A) RNA
Reverse transcription PCR is a specialized technique used to study gene expression by amplifying RNA sequences. The first step involves using the enzyme reverse transcriptase to synthesize a complementary DNA strand from an RNA template. This resulting cDNA is then used as the template for a standard PCR amplification. RT-PCR is essential for detecting viral RNA and measuring cellular mRNA levels.

148. (D) Presence or absence of restriction endonuclease recognition sites
Restriction fragment length polymorphism is a molecular marker technique based on differences in DNA sequences at specific restriction enzyme recognition sites. A mutation within a site can prevent cleavage, while a mutation elsewhere can create a new site. When genomic DNA is digested with restriction enzymes and hybridized with a probe, these variations result in different patterns of fragment lengths on a blot.

149. (B) A single short, arbitrary primer
Random amplified polymorphic DNA is a PCR-based marker technique that does not require prior knowledge of the target DNA sequence. It utilizes a single, short primer, typically ten nucleotides long, with an arbitrary sequence. This primer binds to various complementary sites across the genome. If two sites are close enough and in the correct orientation, the intervening region is amplified, creating a fingerprint.

150. (A) P-2, Q-3, R-4, S-1
Molecular markers are classified based on their underlying principles. RFLP is a non-PCR based technique relying on restriction enzymes and hybridization. RAPD uses single arbitrary primers to amplify unknown regions. AFLP combines the specificity of restriction digestion with the power of PCR through adapter ligation. Finally, SSR markers detect variations in the number of short tandem repeats, providing a highly polymorphic and codominant marking system.

151. (D) SSR (Microsatellites)
Simple sequence repeats, or microsatellites, are highly valuable codominant molecular markers. Because the primers flank a specific repeat locus, the PCR product size depends on the number of repeat units present. This allows researchers to clearly distinguish between homozygous individuals and heterozygotes, who show two distinct bands of different sizes. This codominance makes SSRs ideal for population genetics and linkage mapping studies.

152. (A) Pre-amplification and selective amplification
The AFLP technique involves a complex multi-step process to generate a high-density genetic fingerprint. After restriction digestion and adapter ligation, two rounds of PCR are performed. The first round, called pre-amplification, uses primers that match the adapters plus one selective nucleotide. The second round, selective amplification, uses primers with two or three additional selective nucleotides, which further reduces the number of amplified fragments.

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value of the dependent variable remains constant, resulting in a horizontal line on a graph. This implies that the independent variable is not a useful linear predictor for the outcome in this specific model.

208. (D) Lower energy and longer wavelength than the excitation photon
The fundamental principle of fluorescence is governed by energy loss. When a molecule absorbs an excitation photon, it reaches an excited electronic state. Before emitting a photon to return to the ground state, the molecule loses some energy through vibrational relaxation or internal conversion. Consequently, the emitted photon always has lower energy and a longer wavelength than the original light that was absorbed.

209. (A) The irreversible photochemical destruction of a fluorophore
Photobleaching is a major challenge in fluorescence microscopy and imaging. It occurs when a fluorophore undergoes a permanent chemical change upon repeated excitation, causing it to lose its ability to fluoresce. This destruction is usually caused by reactions with oxygen radicals generated during the excitation process. Researchers often use specialized anti-fade mounting media or lower laser power to minimize this irreversible signal loss.

210. (B) II and III
Confocal microscopy achieves superior resolution and contrast compared to conventional widefield microscopy. Its defining feature is a spatial pinhole placed in the emission path to block light that originates from outside the focal plane. This allows for precise optical sectioning of a sample. By taking multiple sections at different depths, researchers can use computer software to create a three-dimensional reconstruction of the specimen.

211. (A) Cryo-Electron Microscopy (Cryo-EM)
Cryo-electron microscopy is a revolutionary technique that allows researchers to visualize biological molecules in their native, hydrated state. Samples are rapidly frozen in a thin layer of vitreous ice, preserving their natural structure without the need for chemical fixatives, dehydration, or heavy metal stains. This method provides high-resolution images of protein complexes and viruses as they exist in a biological environment.

212. (A) I, II and IV
Inductively coupled plasma optical emission spectroscopy is a highly versatile technique for elemental analysis. It uses a high-temperature argon plasma to atomize and excite the sample. As the excited atoms return to the ground state, they emit light at characteristic wavelengths. This technique is faster and suffers from fewer chemical interferences than flame atomic absorption, and it allows for simultaneous multi-element detection.

213. (B) The number of adjacent, NMR-active nuclei
Spin-spin coupling, also known as J-coupling, is a critical phenomenon in nuclear magnetic resonance spectroscopy. it occurs when the magnetic field of one nucleus influences the energy levels of a neighboring nucleus. This interaction results in the splitting of NMR signals into characteristic patterns like doublets or triplets. These patterns provide vital information about the connectivity and number of adjacent NMR-active nuclei.

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214. (C) The time taken for accelerated ions to travel through a field-free flight tube
A time-of-flight mass analyzer separates ions based on their velocities. All ions are given the same initial kinetic energy by an electric field and then enter a field-free flight tube. Because lighter ions travel faster than heavier ones, they reach the detector sooner. By precisely measuring the time taken for each ion to traverse the tube, the instrument can calculate the mass-to-charge ratio.

215. (A) $t_{1/2} = \dfrac{\ln(2)}{\lambda}$
The half-life of a radioactive isotope is the time required for half of its nuclei to undergo decay. This value is inversely related to the decay constant, which represents the probability of decay per unit time. Mathematically, the half-life is equal to the natural logarithm of two divided by the decay constant. This relationship is a fundamental property of first-order exponential decay processes.

216. (A) It offers a significantly wider linear dynamic range for quantification
Phosphorimaging is a modern alternative to traditional film-based autoradiography. It uses

251. (A) Rejecting a true null hypothesis
In statistical hypothesis testing, a Type I error occurs when a researcher incorrectly rejects a null hypothesis that is actually true. This is often referred to as a "false positive" result, where a difference is claimed when none truly exists. The probability of making a Type I error is represented by the significance level, which is commonly set at point zero five in most scientific research.

252. (C) The probability of correctly rejecting a false null hypothesis $(1 - \beta)$
Statistical power is a measure of a study's ability to detect a real effect or difference when one truly exists. It is mathematically defined as one minus the probability of making a Type II error. A high power ensures that the researcher is likely to correctly reject a false null hypothesis. Power depends on several factors, including the sample size, the effect size, and the chosen significance level.

253. (D) Differential Interference Contrast (DIC) Microscopy
Differential interference contrast microscopy, also known as Nomarski microscopy, is an advanced optical technique used to visualize transparent, unstained specimens. It uses specialized prisms to split light into two paths that pass through the specimen and then recombine. The resulting interference creates a pseudo-three-dimensional image with high contrast and clarity, highlighting the edges and gradients within the cell without the artifacts seen in phase-contrast.

254. (C) Mobile phase linear velocity
The Van Deemter equation is a fundamental model in chromatography that describes the relationship between column efficiency and the flow rate of the mobile phase. It expresses the height equivalent to a theoretical plate as a function of the linear velocity of the mobile phase. By identifying the optimal velocity where the plate height is minimized, researchers can achieve the highest possible separation efficiency for a given column.

255. (B) Multiple distinct flow paths around packing particles of varying size
Eddy diffusion is one of the three primary factors in the Van Deemter equation that contributes to the broadening of peaks in a chromatographic column. It is caused by the fact that different analyte molecules take slightly different paths through the irregular spaces between the packing particles. Because these paths have different lengths, the molecules reach the end of the column at slightly different times, resulting in broader peaks.

256. (D) Step gradient using Ficoll-Paque
Separating mononuclear cells, such as lymphocytes and monocytes, from whole blood requires a specific density gradient technique. A step gradient using Ficoll-Paque is the standard method for this purpose. When blood is layered over the Ficoll and centrifuged, the cells migrate to different levels based on their density. Red blood cells and granulocytes pellet at the bottom, while the mononuclear cells form a distinct layer at the interface.

257. (A) It has undergone transformation to become immortalized and divide indefinitely.
In mammalian tissue culture, a continuous cell line is one that has acquired the ability to divide indefinitely in vitro. This is usually achieved through spontaneous or induced transformation, allowing the cells to bypass the normal biological limit of senescence. These immortalized lines are highly valuable for research because they provide a consistent and inexhaustible supply of identical cells for long-term experiments and large-scale protein production.

258. (C) The T-DNA (Transferred DNA) region
Agrobacterium tumefaciens is a natural genetic engineer used to create transgenic plants. During the infection process, a specific segment of the large Ti plasmid, called the T-DNA, is excised and transferred into the host plant cell. This DNA then integrates into the plant's nuclear genome. In biotechnology, researchers replace the natural genes in the T-DNA with their own genes of interest to create stable genetically modified plants.

259. (A) RNA-dependent DNA polymerase
Reverse transcriptase is a unique enzyme that catalyzes the synthesis of DNA using an RNA molecule as a template. It is technically classified as an RNA-dependent DNA polymerase. This enzyme is naturally used by retroviruses to replicate their genomes, and it has become an essential tool in molecular biology for creating complementary DNA from messenger RNA,

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handle the concentrated cryoprotectants quickly because they can be toxic to the cells at room temperature.

225. (A) Quantifies the initial template concentration by monitoring amplification during the exponential phase
Real-time quantitative PCR differs from standard PCR by monitoring the accumulation of DNA during the entire process rather than only at the end. By measuring the signal during the exponential phase, when the reagents are not limiting, the instrument can precisely calculate the amount of the initial template. This makes qPCR much more accurate and quantitative than traditional end-point PCR methods.

226. (C) The cycle number at which the fluorescent signal clearly exceeds the background threshold
The cycle threshold is the most important value in a qPCR experiment. It represents the specific cycle number at which the fluorescent signal from the accumulating DNA becomes strong enough to be clearly distinguished from the background noise. This value is inversely proportional to the amount of template DNA in the original sample; samples with more DNA will reach the threshold at an earlier cycle.

227. (A) A defense mechanism against invading viral (phage) DNA
Restriction endonucleases are enzymes produced naturally by bacteria as part of their immune system. Their biological role is to recognize and cleave specific foreign DNA sequences, such as those from invading bacteriophages, thereby protecting the cell from infection. To prevent the enzymes from cutting the bacterium's own DNA, the host's recognition sites are typically modified by methylation, which blocks the restriction enzymes.

228. (D) RAPD
Molecular markers are classified as either dominant or codominant. RAPD is a dominant marker system because it is based on the presence or absence of a single band. If an individual is heterozygous, only the dominant band is seen, making it impossible to distinguish them from a homozygous dominant individual. In contrast, codominant markers like SSRs produce different patterns for each genotype, providing more genetic information.

229. (B) Species or generic level
The internal transcribed spacer regions are segments of ribosomal DNA that are transcribed but later removed during RNA processing. Because these regions are not under strong selective pressure, they accumulate mutations more rapidly than the highly conserved rRNA genes. This makes ITS sequences ideal for molecular phylogenetics at lower taxonomic levels, such as distinguishing between different species or genera within a family.

230. (C) Temperature and salt concentration of the wash buffer
Stringency in molecular hybridization refers to the conditions that determine how closely a probe must match the target sequence to remain bound. High stringency conditions, such as high temperature and low salt concentration during the washing steps, ensure that only perfectly matched sequences remain. Lowering the stringency allows the probe to bind to sequences with some degree of mismatch, which is useful in cross-species studies.

231. (D) Block non-specific nucleic acid binding sites on the nylon membrane
Denhardt's solution is a common pre-hybridization reagent used in Southern and Northern blotting. It contains a mixture of polyvinylpyrrolidone, Ficoll, and bovine serum albumin. These components work together to coat the membrane surface and block sites that could otherwise bind the nucleic acid probe non-specifically. This treatment is essential for reducing background noise and ensuring that the probe only binds to the specific target sequences.

232. (A) A purified, labeled interacting partner protein
Far-Western blotting is a specialized technique used to study protein-protein interactions. Unlike a standard Western blot that uses an antibody to detect a protein, far-Western blotting uses a labeled "bait" protein as the probe. This probe is incubated with a membrane containing transferred proteins; if an interaction occurs, the bait protein will bind to its partner on the membrane, allowing for the identification of interacting pairs.

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233. (B) The frequency of individual cells secreting a specific protein (e.g., cytokine)
The enzyme-linked immunospot assay is a highly sensitive method used to measure the immune response at the single-cell level. It identifies individual cells that are actively secreting a specific protein, such as a cytokine or an antibody. The cells are cultured on a plate coated with a capture antibody; as the protein is secreted, it is captured locally, creating a "spot" that can be counted after enzymatic detection.

234. (B) Geometric mean
The geometric mean is a measure of central tendency that is particularly useful for data that follow an exponential or multiplicative pattern, such as population growth rates or fold-changes in gene expression. It is calculated by taking the product of all n observations and then calculating the n-th root. Unlike the arithmetic mean, the geometric mean is less sensitive to extreme outliers in the dataset.

235. (A) 12
Variance and standard deviation are both used to describe the spread of a dataset. Variance is calculated as the average of the squared deviations from the mean. To convert variance back into the original units of measurement, one must take its positive square root. Therefore, if the variance of a particular sample is one hundred forty-four, the calculated standard deviation is exactly twelve.

236. (C) The residuals have a constant variance across all levels of the independent variable
Homoscedasticity is a fundamental assumption in linear regression analysis. It means that the variance of the errors, or residuals, should be constant across all values of the independent predictor variable. If this assumption is violated, a condition called heteroscedasticity occurs, which can lead to inefficient estimates and inaccurate statistical tests. Researchers often use residual plots to check for this constant variance.

237. (D) Mann-Whitney U test
The Mann-Whitney U test is a non-parametric statistical method used to compare the distributions of two independent groups. It is the non-parametric alternative to the independent two-sample t-test and is used when the data do not meet the assumptions of normality. Instead of comparing means, it ranks all the data points and determines if there is a significant difference in the rank order of the groups.

238. (C) Exactly equal
A normal distribution is characterized by its perfectly symmetrical, bell-shaped curve. In this ideal mathematical model, the three primary measures of central tendency the arithmetic mean, the median, and the mode are all located at the exact center of the distribution and are therefore equal to each other. Any significant difference between these values indicates that the data is skewed rather than normally distributed.

239. (B) High correlation among two or more independent variables
Multicollinearity is a potential problem in multiple regression analysis where two or more of the independent variables are highly correlated with each other. This creates redundancy in the model, making it difficult to determine the individual contribution of each predictor to the outcome. High multicollinearity can lead to unstable regression coefficients and large standard errors, reducing the overall reliability of the statistical conclusions.

240. (B) Formulate Null Hypothesis → Calculate F-statistic → Compare to Critical F → Conclude
Statistical hypothesis testing in ANOVA follows a logical, step-by-step procedure. The process begins with the formulation of a null hypothesis, stating that all group means are equal. Next, the F-statistic is calculated from the data. This value is then compared to a critical F-value from a statistical table based on the degrees of freedom. Finally, a conclusion is reached whether to reject the null hypothesis.

241. (A) Two-way ANOVA
A two-way analysis of variance is the appropriate statistical test when an experiment involves two different categorical independent variables. It allows researchers to examine the main effect of each variable on a continuous outcome and, more importantly, to determine if there is a significant interaction effect between them. An interaction occurs when the influence of one variable depends on the level of the second variable.

242. (C) 0.0
The Pearson correlation coefficient measures the degree to which two variables change together linearly. If a scatter plot shows data

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points following a perfectly horizontal line, it means that the value of the dependent variable remains constant regardless of any change in the independent variable. In this case, there is no linear association or predictive relationship between the two, resulting in a correlation coefficient of zero.

243. (A) Placing one or two G or C bases at the 3' end to ensure tight binding at the extension site
A GC clamp is a common design feature used to improve the efficiency and specificity of a PCR reaction. It involves ensuring that the three-prime end of the primer contains one or two guanine or cytosine bases. Because G and C form three hydrogen bonds, they provide a stronger and more stable attachment at the site where DNA polymerase begins synthesis, preventing the primer from breathing.

244. (D) Increasing the agarose concentration
The pore size of an agarose gel is determined by its concentration. A higher percentage agarose gel creates smaller pores, which provides greater resistance to the migration of DNA molecules. This increased sieving effect is particularly useful for resolving very small DNA fragments that would otherwise move too quickly and blur together. Conversely, lower concentration gels are better suited for separating very large DNA molecules.

245. (B) Inside intact cells or chromosomes without prior extraction
Fluorescent in situ hybridization is a powerful cytogenetic technique that identifies specific DNA or RNA sequences directly within their biological context. Unlike blotting methods that require the extraction and purification of nucleic acids, FISH uses fluorescently labeled probes that are hybridized to intact cells or chromosomes on a slide. This allows researchers to visualize the precise physical location of genes within a cell or tissue.

246. (C) It can detect single nucleotide variations (SNPs) based on minuscule differences in melting temperature.
High-resolution melt analysis is an advanced post-PCR technique used to characterize DNA amplicons. It uses specialized saturated fluorescent dyes and high-precision temperature control to monitor DNA denaturation with extreme accuracy. HRM can detect single nucleotide polymorphisms because even a single base pair change will subtly alter the melting temperature and the shape of the resulting fluorescence melt curve, providing a rapid method for genotyping.

247. (D) Polyatomic ions that share the identical mass-to-charge ratio as the target analyte
Isobaric interference is a common challenge in inductively coupled plasma mass spectrometry. It occurs when different ionic species possess the same mass-to-charge ratio as the target analyte, leading to an overlap in the measured signal. These interfering species can be isotopes of different elements or polyatomic ions formed from the plasma gas and the sample matrix. Specialized collision cells are often used to remove these interferences.

248. (A) The fluorescence of single cells passing individually through a laser beam
Flow cytometry is a sophisticated technology used to analyze the physical and chemical characteristics of particles or cells. Unlike standard fluorimetry, which measures the bulk signal from a whole sample, flow cytometry forces a suspension of cells through a narrow nozzle. This allows a laser to excite each individual cell one at a time, providing detailed data on the size, complexity, and fluorescence of every cell in the population.

249. (B) Harmonic Mean
Statistics can be broadly categorized into measures of central tendency and measures of dispersion. Measures of dispersion, such as range, variance, standard deviation, and standard error, describe how spread out the data points are. In contrast, the harmonic mean is a measure of central tendency, similar to the arithmetic mean and the median, used to find the "average" value in a dataset with reciprocal relationships.

250. (A) II, I, III, IV
A standard RNA-Seq experiment follows a logical workflow to profile gene expression. The process begins with the extraction of high-quality RNA from the sample. This is followed by library preparation, where the RNA is converted into cDNA and tagged with adapters. The library is then sequenced using a high-throughput platform. Finally, the resulting raw sequence data is mapped to a reference genome for bioinformatics analysis.

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a specialized imaging plate containing a storage phosphor that captures and stores the energy from radioactive emissions. The primary advantage is its exceptionally wide linear dynamic range, which allows for the accurate quantification of both very faint and very intense signals in the same sample without the saturation seen in photographic film.

217. (B) Non-linear isotherms due to unwanted secondary interactions (e.g., active silanol groups)
Peak tailing is a common problem in chromatography that results in asymmetrical peaks with a long trailing edge. It is often caused by secondary interactions between the analytes and the stationary phase support, such as unreacted acidic silanol groups on silica. These interactions follow a non-linear adsorption isotherm, leading to slower migration of a portion of the analyte and decreasing the overall separation efficiency.

218. (B) Decreased retention times and decreased resolution
In gas chromatography, the column temperature plays a vital role in determining retention. Increasing the temperature ramp rate causes the analytes to spend more time in the gaseous mobile phase, leading to significantly decreased retention times and faster analysis. However, this often comes at the cost of reduced resolution, as closely eluting peaks may overlap when the separation happens too quickly for effective partitioning.

219. (A) N,N'-methylenebisacrylamide (Bis-acrylamide)
The polyacrylamide gel matrix is formed through the chemical polymerization of acrylamide monomers. To create a three-dimensional sieve, a cross-linking agent called N,N-methylenebisacrylamide is added. The ratio of acrylamide to bis-acrylamide determines the pore size of the gel, which can be adjusted to optimize the separation of proteins or nucleic acids based on their specific molecular weight range during electrophoresis.

220. (B) II, III and IV
Agarose gel electrophoresis is the standard method for separating DNA. The migration speed of DNA fragments is inversely proportional to the logarithm of their molecular weight. Supercoiled plasmid DNA is more compact and migrates faster than linear DNA of the same mass. These gels are typically run horizontally in a continuous buffer system, providing a simple and effective way to analyze genomic or plasmid DNA.

221. (D) Reaches a steady state where further centrifugation time does not alter band position
Isopycnic centrifugation is an equilibrium technique where particles migrate until they reach a position in the gradient that matches their own buoyant density. Once this equilibrium is reached, the particles remain in stable bands even if the centrifugation is continued for much longer. In contrast, rate-zonal centrifugation is a time-dependent process where separation is based on speed; if continued too long, all particles would eventually pellet.

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222. (C) Selecting and regenerating whole transgenic plants from transformed single cells
Tissue culture is an indispensable component of plant genetic engineering. After Agrobacterium-mediated transformation, only a small fraction of the cells will have successfully incorporated the new DNA. Tissue culture techniques allow for the selective growth of these transformed cells on a specialized medium. Furthermore, the regenerative capacity of these cells is harnessed to produce whole, fertile transgenic plants from a single transformed cell.

223. (D) Arising spontaneously among plants regenerated from long-term in vitro tissue cultures
Somaclonal variation refers to the genetic or epigenetic changes that occur spontaneously in plants regenerated from tissue culture. This variation can be caused by the stresses of the in vitro environment, including high levels of growth regulators and the dedifferentiation process. While often considered a problem for clonal propagation, it can be a source of novel traits for plant improvement and breeding.

224. (A) I, II and III
Successful cryopreservation requires careful control over the freezing process. Vitrification is a method that entirely avoids ice crystal formation by using high concentrations of cryoprotectants and rapid cooling. Traditional slow-freezing methods typically use a controlled rate of one degree per minute. It is vital to

allowing for the study and cloning of eukaryotic gene transcripts.

260. (A) Both A and R are true and R is the correct explanation of A.
In gas chromatography, the separation of analytes depends heavily on their relative volatility. Compounds that are more volatile have lower boiling points and higher vapor pressures, which causes them to partition more readily into the gaseous mobile phase. As a result, these volatile molecules spend less time interacting with the stationary phase and travel through the column more quickly, eluting earlier than less volatile compounds.

261. (B) Its ability to add a single 3'-adenine overhang to PCR products
Taq DNA polymerase has a unique non-template-dependent terminal transferase activity. During the final stage of PCR, the enzyme often adds a single adenine nucleotide to the three-prime ends of each amplified DNA strand. This characteristic "A-overhang" is exploited in TA cloning, where the PCR products are directly ligated into specialized vectors that have complementary three-prime thymine overhangs, greatly simplifying the gene cloning process.

262. (C) Provide a statistical confidence assessment for the branching clades in the tree
Bootstrapping is a statistical technique used in phylogenetics to evaluate the reliability of the branching patterns in a phylogenetic tree. It involves repeatedly re-sampling the original sequence alignment to create a set of pseudo-datasets, which are each used to build a new tree. The percentage of these trees that support a particular branch, or clade, provides a measure of confidence in that evolutionary relationship.

263. (D) Peptide Mass Fingerprinting
Peptide mass fingerprinting is a standard proteomic technique used to identify unknown proteins. The protein is first digested with a specific protease, such as trypsin, to create a set of peptides. The masses of these peptides are measured using a mass spectrometer and then compared against a database of theoretical peptide masses derived from known protein sequences. A significant match allows for the definitive identification of the protein.

264. (A) Indirect Immunofluorescence
Indirect immunofluorescence is a two-step detection technique used to visualize the location of specific antigens in cells or tissues. First, an unlabeled primary antibody binds specifically to the target antigen. Then, a fluorescently labeled secondary antibody is added, which binds to the constant region of the primary antibody. This approach is more sensitive than direct methods because multiple secondary antibodies can bind to a single primary antibody, amplifying the signal.

265. (B) Amplification efficiency drops dramatically due to reagent depletion and product inhibition.
In a standard PCR reaction, the accumulation of DNA eventually slows down and enters a plateau phase. This happens because the essential reagents, such as nucleotides and primers, become depleted. Additionally, the increasing concentration of the PCR product can inhibit the DNA polymerase, and the accumulating inorganic pyrophosphate can drive the reaction backward. This makes end-point PCR unsuitable for the accurate quantification of the original amount of template DNA.

266. (B) ChIP-Seq (Chromatin Immunoprecipitation Sequencing)
ChIP-Seq is a powerful technique used to map the interaction between specific proteins, such as transcription factors, and the genome. It involves chemically cross-linking proteins to DNA, followed by fragmentation and immunoprecipitation using a specific antibody for the protein of interest. The captured DNA fragments are then sequenced, providing a high-resolution, genome-wide map of all the binding sites for that specific protein in a biological sample.

267. (A) Relative size
In flow cytometry, the light from a laser is scattered by individual cells as they pass through the beam. Forward scatter refers to the light that is scattered at a small angle relative to the incident laser path. The intensity of this forward scatter signal is primarily proportional to the cross-sectional area and the overall volume of the cell, providing a reliable measure of the cell's relative size.

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285. (D) Coating DNA onto tungsten or gold microparticles and firing them at high velocity
Biolistics, or the gene gun method, is a physical technique for delivering DNA into plant cells, especially those that are difficult to transform with Agrobacterium. The DNA of interest is coated onto tiny microparticles made of heavy metals like tungsten or gold. These particles are then accelerated to high velocities using pressurized helium and fired into the target tissue, where the DNA can be released and integrate into the host genome.

286. (C) Protoplasts derived from somatic cells of two different plant species
Somatic hybridization is a technique that bypasses the natural barriers of sexual reproduction to create new plant hybrids. It involves the induced fusion of protoplasts from two different species or varieties. Because these protoplasts are derived from somatic cells, the resulting hybrid contains the nuclear and cytoplasmic genetic material from both parents. This method is used to transfer traits like disease resistance or stress tolerance between species that cannot be crossed normally.

287. (B) Polyethylene glycol (PEG)
Protoplast fusion is the critical step in somatic hybridization, but it does not occur spontaneously. Chemical fusogens are required to bring the protoplasts together and induce the membranes to merge. Polyethylene glycol is the most effective and widely used chemical for this purpose. It acts as a molecular bridge, causing the protoplasts to aggregate and then facilitating the fusion of the lipid bilayers, resulting in the formation of a hybrid cell.

288. (D) Somatic embryos or shoot buds
Synthetic seeds are a biotechnological innovation designed for the efficient propagation and storage of elite plant varieties. They are created by encapsulating vegetative structures, such as somatic embryos, shoot buds, or microshoots, in a protective, nutrient-rich hydrogel like calcium alginate. This encapsulation provides physical protection and a source of nutrients, allowing the synthetic seeds to be handled like natural seeds and grown into whole plants under sterile or non-sterile conditions.

289. (A) Possess poorly developed cuticular wax and non-functional stomata
Acclimatization is a vital final step for plants produced through tissue culture. While in vitro, plantlets grow in an environment with one hundred percent humidity and high nutrients. As a result, they develop thin cuticular waxes and non-functional stomata, making them extremely susceptible to desiccation. During the hardening process, the plants are gradually exposed to lower humidity and higher light, allowing them to strengthen their physiological defenses before transplantation to the field.

290. (C) It enhances the host's immune response to the antigen without being antigenic itself.
An adjuvant is a chemical or biological agent injected alongside an antigen to increase the strength and duration of the immune response. Adjuvants work by creating a depot of the antigen at the injection site for slow release and by stimulating the recruitment of immune cells to the area. This results in the production of a higher titer of antibodies, which is essential for the commercial generation of polyclonal antibodies for research and diagnostics.

291. (A) Monoclonal antibodies
Hybridoma technology is the standard method for producing monoclonal antibodies. It involves the fusion of antibody-producing B-cells from an immunized animal with immortal myeloma cells. Each resulting hybridoma clone produces a single type of antibody that is specific for only one epitope on the antigen. Because these cells can be grown indefinitely in culture, they provide a consistent and permanent source of highly specific antibodies for diagnostic and therapeutic use.

292. (D) Immortality in cell culture
In the creation of a hybridoma, each parent cell provides a critical characteristic. The B-lymphocyte provides the genetic code for the specific antibody of interest, but it has a very limited lifespan in culture. In contrast, the myeloma cell is a type of cancer cell that can divide indefinitely. By fusing these two, the resulting hybridoma combines the antibody specificity of the B-cell with the immortality of the myeloma cell.

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blocks in the statistical analysis, the remaining unexplained error variance is reduced, making the test more sensitive to the actual effects of the treatments.

277. (B) The error terms do not have constant variance.
Heteroscedasticity is a statistical condition in regression analysis where the spread or variance of the residuals is not constant across all levels of the independent variable. This violation of the homoscedasticity assumption means that the model's predictions may be more accurate in some ranges than in others. Heteroscedasticity can often be detected by looking for a cone or fan-shaped pattern in a residual plot and may require data transformation to correct.

278. (C) It divides a ranked dataset perfectly into two equal halves.
The median is a robust measure of central tendency that represents the middle value of a dataset when all observations are ranked in numerical order. It divides the population perfectly into two equal halves, with fifty percent of the values above it and fifty percent below. Unlike the arithmetic mean, the median is not significantly influenced by extreme outliers, making it a more reliable measure for highly skewed data distributions.

279. (C) The third quartile (Q3) and the first quartile (Q1)
The interquartile range is a measure of statistical dispersion that describes the spread of the middle fifty percent of a dataset. It is calculated as the difference between the third quartile, which is the seventy-fifth percentile, and the first quartile, which is the twenty-fifth percentile. Because it ignores the extreme ends of the distribution, the IQR is highly resistant to outliers and is a standard component of box-and-whisker plots.

280. (A) P-2, Q-4, R-1, S-3
Chromatography utilizes various detectors depending on the nature of the analytes and the mobile phase. Flame ionization is the standard detector for gas chromatography. Refractive index detectors are used for analytes with poor UV absorption, such as sugars. Photodiode arrays provide full-spectrum data in HPLC. Finally, mass spectrometers offer the ultimate capability for molecular identification by providing detailed information about the mass-to-charge ratio of the analytes.

281. (B) Multiple distinct primer pairs are used in a single reaction tube to amplify multiple targets.
Multiplex PCR is a specialized technique that allows for the simultaneous amplification of multiple target sequences in a single reaction tube. This is achieved by including several distinct primer pairs, each specific to a different DNA region. It is highly efficient for pathogen detection and forensic analysis but requires careful optimization of primer concentrations and annealing temperatures to ensure that all targets are amplified with similar efficiency.

282. (B) Differentiate between two ions with closely identical mass-to-charge ($\frac{m}{z}$) ratios
Resolution is a key performance metric for any mass spectrometer. It is defined as the instrument's ability to distinguish between two ions that have very similar mass-to-charge ratios. High-resolution instruments can separate isotopes and complex molecules that differ by only a fraction of an atomic mass unit. This capability is essential for the accurate identification of unknown compounds and for analyzing complex biological mixtures where many similar species are present.

283. (A) Slower, due to a higher frictional coefficient
In centrifugation, the sedimentation rate of a macromolecule depends not only on its mass and density but also on its shape. An elongated, fibrous protein has a much larger surface area and experiences more hydrodynamic drag than a compact, spherical protein of the same mass. This result in a higher frictional coefficient for the elongated molecule, causing it to sediment significantly more slowly through the medium in a centrifugal field.

284. (C) Digoxigenin (DIG) system
The digoxigenin system is a widely used non-radioactive method for labeling and detecting nucleic acids. DIG is a steroid molecule found only in digitalis plants; it is incorporated into DNA or RNA probes as a chemical tag. Detection is achieved using a specific high-affinity antibody conjugated to an enzyme, such as alkaline phosphatase. This system provides high sensitivity and low background, making it a safe and effective alternative to radioactive phosphorus.

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268. (C) Internal complexity or granularity
Side scatter in flow cytometry describes the light that is scattered at a large angle, usually ninety degrees, from the incident laser beam. The intensity of this signal is determined by the internal structural complexity of the cell, including the presence of a nucleus, granules, and other organelles. Measuring both forward and side scatter allows researchers to distinguish between different cell types, such as neutrophils and lymphocytes, in a mixed population.

269. (D) A-T rich regions in double-stranded DNA
DAPI is a popular fluorescent stain used to visualize the nuclei of cells. It is a minor groove binder that shows a strong and selective affinity for regions of double-stranded DNA that are rich in adenine and thymine base pairs. When bound to DNA, its fluorescence increases significantly, emitting bright blue light under ultraviolet excitation. This sensitivity and specificity make it an ideal tool for nuclear localization and DNA quantification.

270. (C) Known analyte concentrations against their corresponding measured analytical signals
A standard curve is a fundamental calibration tool used in quantitative biochemistry. It is created by measuring the analytical signal, such as absorbance or fluorescence, for a series of samples with known concentrations of the analyte. By plotting these values, a mathematical relationship—usually linear—is established. This curve then allows researchers to determine the unknown concentration of an experimental sample by mapping its signal back to the corresponding concentration value.

271. (B) To provide an unbiased estimate of the population variance
When calculating variance for a sample of data, the sum of the squared deviations from the mean is divided by n minus one rather than the total number of observations. This is known as Bessel's correction. Using n minus one compensates for the fact that the sample mean is an estimate of the true population mean, providing a mathematically unbiased estimate of the overall population variance.

272. (D) The point representing the mean of X and the mean of Y $(\bar{X}, \bar{Y})$
Ordinary least squares regression is a statistical method that identifies the line that minimizes the total squared error of the predictions. One of the fundamental mathematical properties of an OLS regression line is that it must pass through the centroid of the data. This means that the line will always intersect the point defined by the arithmetic mean of the independent variable and the arithmetic mean of the dependent variable.

273. (A) Ensure the data meets the assumptions of normality and homogeneity of variance
Parametric statistical tests like ANOVA require that the data follow a normal distribution and have equal variances among groups. Biological data often violate these assumptions. To address this, researchers apply data transformations, such as the log or square root transformation. These mathematical adjustments help to stabilize the variance and normalize the distribution, ensuring that the results of the subsequent statistical analysis are accurate and valid.

274. (C) Y-axis (Ordinate)
In scientific graphing and statistical analysis, variables are plotted on specific axes to represent their relationship. Conventionally, the independent variable, which is controlled or measured to observe its effect, is plotted on the horizontal X-axis. The dependent variable, which is the outcome or response being measured, is always plotted on the vertical Y-axis. This standard orientation allows for the clear visualization of how the dependent variable responds to changes in the predictor.

275. (A) Exact +1.0 or exact -1.0
A deterministic mathematical relationship exists when the value of one variable is perfectly predictable from the value of another. In such cases, all the data points in a scatter plot would fall exactly on a straight line. Depending on whether the variables increase together or in opposite directions, the Pearson correlation coefficient will be exactly positive one point zero or negative one point zero, representing the maximum possible linear association.

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276. (D) Control known variability to reduce error variance
Blocking is a powerful experimental design strategy used to increase the precision of a study. It involves grouping experimental units that are similar in some way—such as being in the same field or from the same batch—into blocks. By accounting for the variation between these

293. (B) Selectively kill unfused myeloma cells while allowing hybridomas to survive
HAT medium is used to select for successful hybridomas after the fusion process. Myeloma cells are chosen that are deficient in an enzyme required for the salvage pathway of DNA synthesis. Aminopterin in the HAT medium blocks the de novo pathway, while hypoxanthine and thymidine allow the salvage pathway to function. Only the hybridomas, which have the missing enzyme from the B-cell parent, can survive and grow under these conditions.

294. (C) IgG
Immunoglobulin G is the most abundant antibody class in human serum, accounting for approximately seventy-five percent of all circulating antibodies. It plays a central role in the secondary immune response and provides long-term protection against pathogens. Due to its high concentration, stability, and strong binding affinity, IgG is the most common target for detection in clinical assays and is widely used to develop secondary antibodies for molecular biology research.

295. (D) Multiple distinct epitopes on the same antigen
Polyclonal antibodies are a collection of different antibodies produced by multiple B-cell lineages in response to an antigen. Because an antigen usually has many different structural features, or epitopes, the immune system produces a diverse range of antibodies that each bind to a different part of the molecule. This makes polyclonal antibodies highly effective for detecting proteins in complex mixtures, as they can bind the target even if some epitopes are modified.

296. (A) Mitochondrial oxidoreductase enzymes
MTT and XTT assays are common colorimetric methods used to measure cellular metabolic activity and viability. These tetrazolium salts are reduced by mitochondrial oxidoreductase enzymes in living cells, forming a colored product—purple formazan for MTT and orange for XTT. The intensity of the color produced is directly proportional to the number of metabolically active, living cells in the sample, providing a rapid way to screen drugs for toxicity.

297. (B) Exactly two distinct variables measured for each observational unit
Bivariate data is a term in statistics used to describe a dataset that involves the study of two different variables simultaneously. For each individual unit or observation in the study, two distinct measurements are taken, such as height and weight or temperature and growth rate. The primary purpose of collecting bivariate data is to explore and quantify the mathematical relationship or association between the two variables using correlation and regression techniques.

298. (B) Covariance
Covariance is a statistical measure that describes the joint variability of two random variables. It indicates the direction of the linear relationship between them; a positive covariance means both variables tend to increase together, while a negative covariance means they move in opposite directions. Mathematically, it serves as the numerator in the calculation of the Pearson correlation coefficient, which provides the standardized version of this linear dependence.

299. (A) A horizontal line with a slope of zero
If the correlation between an independent variable X and a dependent variable Y is zero, there is no linear association between them. In this situation, the best-fit regression line that predicts Y from X will be a horizontal line. This line has a slope of zero, indicating that the predicted value of Y is simply its mean, regardless of the value of X. This confirms that X has no linear predictive power for Y.

300. (B) $s = \sqrt{s^2}$
The relationship between the variance and the standard deviation of a dataset is fundamentally based on a square root function. The standard deviation represents the average dispersion of values in the original units, while the variance represents the average of the squared deviations from the mean. Therefore, standard deviation is the positive square root of variance. This conversion is necessary to restore the spread measurement to the original scale of the data.

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2021

37. Based on their molecular structure, wheat prolamins (gliadins) are characterized by exceptionally high contents of which two amino acids?
(A) Lysine and Tryptophan
(B) Glutamine and Proline
(C) Aspartic acid and Glycine
(D) Histidine and Arginine

2013

38. The distinct pungent flavor of crushed garlic is primarily due to the enzymatic conversion of alliin into which sulfur-containing compound?
(A) Glucosinolate
(B) Sinigrin
(C) Allicin
(D) Isothiocyanate

2008

39. During the ripening of climacteric fruits, the sudden burst in cellular respiration is tightly coupled with a sharp increase in the biosynthesis of which hormone?
(A) Auxin
(B) Gibberellic acid
(C) Abscisic acid
(D) Ethylene

2013

40. Which enzymatic degradation process is primarily responsible for the post-harvest softening of fruit tissues?
(A) Depolymerization of cell wall pectin by polygalacturonase
(B) Hydrolysis of structural lipids via actions of lipoxygenases
(C) Breakdown of chlorophyll molecules triggered by chlorophyllase
(D) Oxidation of polyphenols catalyzed by the polyphenol oxidase

2025

41. Biofortification of crops with iron and zinc can be achieved through classical breeding or metabolic engineering. A major challenge to the bioavailability of these accumulated minerals is the co-presence of which endogenous compound?
(A) Ascorbic acid
(B) Phytic acid
(C) Riboflavin
(D) Starch

2021

42. Flavonoids, a major class of plant polyphenols, typically share which core structural skeleton?
(A) A straight-chain aliphatic structure with multiple conjugated double bonds
(B) A 15-carbon skeleton arranged in a (C6-C3-C6) phenyl ring configuration
(C) A tetrapyrrole ring system containing a central metal ion in the middle
(D) A highly branched polyisoprenoid structure containing multiple chains

2021

43. Which processing method is generally most effective at destroying Bowman-Birk protease inhibitors present in raw soybeans?
(A) Soaking in cold water for 12 hours
(B) Sun drying at ambient temperature
(C) Fermentation with lactic acid bacteria
(D) Thermal processing (e.g., boiling or autoclaving)

2005

44. Aflatoxin B1 is a highly potent hepatocarcinogenic mycotoxin produced primarily by species of which fungal genus?
(A) Fusarium
(B) Penicillium
(C) Aspergillus
(D) Claviceps

2019

45. Lactose intolerance is fundamentally a metabolic intolerance rather than a true food allergy because it is caused by:
(A) An IgE-mediated immune response to proteins found in milk
(B) The enzymatic deficiency of lactase in the small intestine
(C) A T-cell mediated autoimmune reaction directed at lactose
(D) The cross-reactivity of lactose with the histamine receptors

2003

46. Arrange the following steps of the protein digestion and absorption sequence in the correct physiological order:
I. Activation of trypsinogen to trypsin by enteropeptidase
II. Denaturation of dietary proteins by gastric hydrochloric acid
III. Hydrolysis of peptide bonds by pepsin
IV. Active transport of dipeptides and free amino acids into enterocytes
(A) II, III, I, IV
(B) III, II, I, IV
(C) II, I, III, IV

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(B) The breakdown of hydroperoxides into volatile organic compounds
(C) The addition of molecular oxygen to form a new peroxyl radical
(D) The reaction of two lipid radicals to form non-radical products

2023

9. Which essential fatty acid serves as the primary biochemical precursor for the synthesis of arachidonic acid (C20:4, n-6) in humans?
(A) Alpha-linolenic acid
(B) Linoleic acid
(C) Eicosapentaenoic acid
(D) Oleic acid

2015

10. Match the essential trace elements (List I) with their primary metalloenzyme or functional role (List II).
List I : (Elements)
P. Zinc
Q. Selenium
R. Copper
S. Molybdenum
List II : (Role)
1. Glutathione peroxidase
2. Cytochrome c oxidase
3. Carbonic anhydrase
4. Xanthine oxidase
(A) P-2, Q-1, R-4, S-3
(B) P-3, Q-1, R-2, S-4
(C) P-1, Q-3, R-2, S-4
(D) P-3, Q-4, R-2, S-1

2018

11. Which intrinsic factor most significantly downregulates the intestinal absorption of non-heme dietary iron?
(A) High levels of circulating hepcidin
(B) Increased expression of ferroportin on enterocytes
(C) High concentration of gastric hydrochloric acid
(D) Elevated levels of duodenal cytochrome b

2007

12. In the biochemical profile of most cereal grains, which specific essential amino acid is typically the limiting amino acid?
(A) Methionine
(B) Tryptophan
(C) Lysine
(D) Leucine

2006

13. Based on Osborne's solubility classification, which fraction represents the primary storage proteins in legume seeds?
(A) Albumins
(B) Prolamins
(C) Glutelins
(D) Globulins

2025

14. Which secondary metabolite is primarily responsible for the characteristic red pigmentation in tomatoes and watermelons?
(A) Lutein
(B) Beta-carotene
(C) Lycopene
(D) Zeaxanthin

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2006

15. The biochemical synthesis of ethylene during climacteric fruit ripening utilizes which amino acid as its primary precursor?
(A) Tyrosine
(B) Methionine
(C) Tryptophan
(D) Phenylalanine

2004

16. During the post-harvest storage of potatoes at low temperatures (below 4°C), which specific biochemical phenomenon commonly occurs?
(A) Rapid starch synthesis leading to noticeable textural hardening
(B) Immediate degradation of solanine into harmless alkaloids
(C) Complete suppression of polyphenol oxidase activity permanently
(D) Accumulation of reducing sugars caused by cold-induced sweetening

2006

17. The metabolic engineering strategy used in the development of "Golden Rice" aimed to increase the endosperm concentration of which specific compound?
(A) Provitamin A (β-carotene)
(B) Essential ascorbic acid
(C) Long-chain fatty acids
(D) Bioavailable iron ions

2023

18. Which structural feature of plant polyphenolics is principally responsible for their free-radical scavenging capability?
(A) The presence of many aliphatic side chains in the structure

2023

79. The biological role of chaperone proteins in dietary sources relates primarily to which aspect of protein biochemistry?
(A) Assisting in the correct folding of newly synthesized polypeptide chains
(B) Transporting lipids across cell membranes
(C) Serving as the primary oxygen carriers
(D) Providing long-term nitrogen storage in seeds

2006

80. The amino acid score (AAS) of a food protein is determined by comparing its essential amino acid profile against which standard?
(A) The profile of essential amino acids in human serum albumin
(B) The profile of amino acids in a standard beef reference
(C) The total nitrogen content of a purely synthetic protein
(D) The amino acid pattern of an infant as defined by FAO/WHO

2021

81. The term "oxidative rancidity" is biochemically defined by the degradation of which specific structures within food lipids?
(A) Saturated alkyl chains
(B) Carbon-carbon double bonds in unsaturated fatty acids
(C) Ester linkages between glycerol and fatty acids
(D) Phosphate groups in phospholipids

2016

82. Match the essential fatty acid or its derivative (List I) with its specific biochemical classification (List II).
List I : (Fatty Acid)
P. Arachidonic acid
Q. Eicosapentaenoic acid
R. Alpha-linolenic acid
S. Linoleic acid
List II : (Classification)
1. Omega-3 precursor
2. Omega-6 precursor
3. Omega-3 long-chain derivative
4. Omega-6 long-chain derivative
(A) P-4, Q-3, R-1, S-2
(B) P-2, Q-1, R-4, S-3
(C) P-3, Q-4, R-2, S-1
(D) P-1, Q-2, R-3, S-4

2024

83. The clinical manifestation of severe dietary iodine deficiency in adult populations is predominantly:
(A) Osteomalacia
(B) Pellagra
(C) Megaloblastic anemia
(D) Goiter

2023

84. Which extrinsic factor effectively increases the intestinal absorption of dietary non-heme iron?
(A) High consumption of dietary polyphenols like tannins
(B) Ingestion of high doses of calcium supplements
(C) Concomitant intake of ascorbic acid (Vitamin C)
(D) Presence of dietary phytic acid

2005

85. The biochemical composition of soybean is unique among agricultural pulses because it contains approximately:
(A) 40% protein and 20% oil
(B) 20% protein and 40% oil
(C) 10% protein and 70% carbohydrates
(D) 80% protein and 2% oil

2015

86. Which structural feature defines the cereal storage proteins classified as glutelins, such as the glutenin fraction of wheat?
(A) Solubility in pure water at neutral pH
(B) Absence of hydrophobic amino acid residues
(C) Extreme sensitivity to breakdown by salivary amylase
(D) Polymeric networks cross-linked by disulfide bonds

2024

87. The distinct green pigment in unripe fruits is primarily composed of chlorophyll. During ripening, the disappearance of green color is biochemically initiated by:
(A) The synthesis of anthocyanins
(B) The binding of ethylene directly to the magnesium ion
(C) The cleavage of the phytol tail by the enzyme chlorophyllase
(D) The oxidation of carotenes

2014

88. Non-climacteric fruits differ from climacteric fruits fundamentally in their ripening physiology. Which of the following is a classic example of a non-climacteric fruit?

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2014

28. Which of the following best describes the "Glycemic Load" (GL) of a specific food portion?
(A) The measure of the exact amount of insulin secreted per gram of food
(B) The product of the food's Glycemic Index and its total weight in grams
(C) The GI times the grams of carbohydrate in a portion, divided by 100
(D) The mathematical inverse of the Glycemic Index for a specific food item

2006

29. Soluble dietary fibers such as pectin exert physiological health impacts primarily through which of the following biochemical pathways?
(A) Increasing the physical abrasion of the intestinal lining walls
(B) Completing enzymatic hydrolysis via the action of pancreatic amylase
(C) Direct absorption into the portal vein to lower the blood pressure
(D) Fermentation by colonic microbiota to produce short-chain fatty acids

2011

30. Which specific property distinguishes an incomplete dietary protein from a complete dietary protein?
(A) An incomplete protein lacks a tertiary structure.
(B) An incomplete protein cannot be hydrolyzed by pepsin.
(C) An incomplete protein is deficient in one or more essential amino acids.
(D) An incomplete protein lacks nitrogen in its chemical backbone.

2008

31. The Protein Efficiency Ratio (PER) is a biological evaluation method that measures protein quality by calculating:
(A) The percentage of absorbed nitrogen retained by the body system
(B) The weight gain of a test animal divided by the protein intake
(C) The fecal nitrogen loss minus the urinary nitrogen loss detected
(D) The true digestibility of the protein within the small intestine

2008

32. In lipid chemistry, the "Iodine Value" is a physicochemical index used primarily to determine which property of a fat or oil?
(A) The average molecular weight of the triacylglycerols
(B) The amount of free fatty acids indicating hydrolytic rancidity
(C) The solid fat content at a given temperature
(D) The degree of unsaturation of the fatty acids

2013

33. Omega-3 essential fatty acids, such as docosahexaenoic acid (DHA), have significant biochemical roles in human health, particularly in maintaining the structural integrity of which tissue?
(A) Retinal photoreceptors and neuronal membranes
(B) Calcified bone trabeculae
(C) Skeletal muscle myofibrils
(D) Hepatic parenchymal cells

2018

34. Consider the following statements regarding macro-minerals and trace elements:
I. Calcium is a macro-mineral vital for muscle contraction and blood coagulation.
II. Iodine is a trace element essential for the synthesis of thyroxine.
III. Magnesium acts as a critical cofactor for ATP-dependent enzymatic reactions.
IV. Iron is a macro-mineral responsible for regulating extracellular fluid volume.
Which of the above statement(s) is/are INCORRECT?
(A) I, II and III
(B) II, III and IV
(C) I, III and IV
(D) Only IV

NODIA

2010

35. The intestinal absorption of dietary calcium is most effectively enhanced by the active form of which vitamin?
(A) Vitamin D (1,25-dihydroxycholecalciferol)
(B) Vitamin C
(C) Vitamin A
(D) Vitamin K

2015

36. Among the major food pulses, which amino acid is typically present in limiting amounts, necessitating complementation with cereal grains?
(A) Lysine
(B) Arginine
(C) Glutamic acid
(D) Methionine

CHAPTER 06

Biochemistry of Food Grains, Fruits and Vegetables

2013

1. Which of the following best defines the Specific Dynamic Action (SDA) of food?
(A) The surplus heat produced by the body during the digestion, absorption, and metabolism of nutrients
(B) The obligatory energy expenditure for maintaining cellular membrane potentials
(C) The total energy released when one gram of food is completely combusted in a bomb calorimeter
(D) The baseline energy required to maintain respiration and circulation at complete rest

2001

2. According to Recommended Dietary Allowances (RDA) principles, the "safe level of intake" for a nutrient is typically calculated to meet the requirements of what percentage of the healthy population?
(A) 50 percent
(B) 75 percent
(C) 97.5 percent
(D) 100 percent

2009

3. Which of the following is a homopolysaccharide composed entirely of fructose units linked by β(2 $\rightarrow$1) glycosidic bonds?
(A) Inulin
(B) Amylopectin
(C) Glycogen
(D) Cellulose

2021

4. The Glycemic Index (GI) of a food is primarily influenced by which of the following physiological and biochemical factors?
(A) The absolute amount of dietary cholesterol present in the food matrix
(B) The ratio of essential to non-essential amino acids in the dietary protein fraction
(C) The specific dynamic action generated by the lipid content of the meal
(D) The rate at which the food is digested and its carbohydrate content is absorbed as glucose

2016

5. In the context of dietary fibers, what is the primary physiological impact of high-viscosity soluble fibers such as β-glucans in the upper gastrointestinal tract?
(A) They accelerate gastric emptying and increase rapid glucose spikes
(B) They delay gastric emptying and attenuate postprandial blood glucose absorption
(C) They selectively bind to calcium to prevent its intestinal absorption
(D) They undergo minimal bacterial fermentation in the colon

2019

6. Which of the following is an INCORRECT statement regarding the classification of dietary proteins?
(A) Simple proteins yield only amino acids upon complete hydrolysis.
(B) Nucleoproteins are conjugated proteins containing nucleic acids.
(C) Derived proteins are naturally occurring complex proteins found intact in raw foods.
(D) Phosphoproteins contain covalently bound phosphate groups.

2006

7. The Digestible Indispensable Amino Acid Score (DIAAS) improves upon the Protein Digestibility Corrected Amino Acid Score (PDCAAS) by measuring amino acid digestibility at which specific anatomical location?
(A) The stomach
(B) The ascending colon
(C) The rectum
(D) The terminal ileum

2018

8. During the initiation phase of lipid autoxidation, which specific biochemical event occurs first?
(A) The abstraction of a hydrogen atom from a methylene carbon

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(D) I, II, III, IV

2010

47. A "synbiotic" functional food product is best defined by which of the following mechanisms of action?
(A) The synergistic combination of two different strains of probiotic bacteria
(B) A probiotic paired with a prebiotic that selectively favors its growth
(C) The administration of prebiotics that competitively inhibit gut pathogens
(D) A pharmaceutical preparation of synthetic vitamins and trace minerals

2008

48. Curcumin, a well-documented nutraceutical extracted from turmeric, exerts its primary anti-inflammatory benefit by inhibiting which signaling pathway?
(A) Cyclic AMP/PKA pathway
(B) Wnt/β-catenin pathway
(C) Cyclooxygenase-2 (COX-2) and Lipoxygenase (LOX) pathways
(D) Insulin receptor substrate (IRS) cascade

2021

49. In food additive regulations, what does the acronym "GRAS" stand for?
(A) Generally Recognized As Safe
(B) Government Regulated Additive Substance
(C) Globally Registered Artificial Sweetener
(D) Guaranteed Reliable Analytical Standard

2023

50. The specific dynamic action (SDA) is highest for which of the following macronutrients?
(A) Carbohydrates
(B) Lipids
(C) Water
(D) Proteins

2011

51. The mathematical calculation of a balanced diet relies heavily on the Estimated Energy Requirement (EER). Which component constitutes the largest fraction of total daily energy expenditure in sedentary adults?
(A) Thermic effect of food
(B) Basal metabolic rate
(C) Non-exercise activity thermogenesis
(D) Adaptive thermogenesis

2016

52. Which physicochemical characteristic is responsible for the formation of resistant starch (Type III) during the cooking and subsequent cooling of starchy foods?
(A) Gelatinization
(B) Dextrinization
(C) Retrogradation
(D) Caramelization

2022

53. A food item has a Glycemic Index of 80 and contains 15 grams of available carbohydrates per serving. What is the Glycemic Load of one serving?
(A) 8
(B) 12
(C) 15
(D) 120

2015

54. Which of the following is a key physiological consequence of consuming a diet strictly lacking in insoluble dietary fiber?
(A) Decreased incidence of gallstones
(B) Reduced overall caloric intake
(C) Impaired absorption of fat-soluble vitamins
(D) Increased transit time of chyme through the gastrointestinal tract

2012

55. In the context of protein classification, hemoglobin is classified structurally as a:
(A) Simple fibrous protein
(B) Conjugated metalloprotein
(C) Simple globular protein
(D) Derived phosphoprotein

2015

56. The Net Protein Utilization (NPU) metric differs from the Biological Value (BV) primarily because NPU explicitly accounts for which variable?
(A) The specific limiting amino acid concentration
(B) The body surface area of the individual
(C) The true digestibility of the protein
(D) The total energy provided by the protein

2015

57. The onset of hydrolytic rancidity in food lipids is mediated by which class of enzymes?
(A) Lipoxygenases
(B) Phospholipases
(C) Peroxidases
(D) Lipases

NODIA

2021

58. Consider the following statements regarding saturated and unsaturated fatty acids:
I. Saturated fatty acids contain no carbon-

carbon double bonds.
II. Trans-unsaturated fatty acids generally exhibit lower melting points than their cis-isomers.
III. Unsaturated fatty acids are more susceptible to autoxidation than saturated fatty acids.
IV. Stearic acid is an example of an 18-carbon saturated fatty acid.

Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and IV
(C) I, III and IV
(D) I, II and IV

2021

59. Which trace element is fundamentally required as a core component of the cyanocobalamin (Vitamin B12) molecule?
(A) Copper
(B) Cobalt
(C) Iron
(D) Zinc

2019

60. The bioavailability of dietary calcium is substantially reduced by the presence of high dietary levels of which organic acid?
(A) Citric acid
(B) Oxalic acid
(C) Ascorbic acid
(D) Malic acid

2015

61. Oilseeds such as sunflower and safflower are nutritionally valued primarily due to their high concentration of:
(A) Linoleic acid and vitamin E
(B) Omega-3 essential fatty acids
(C) Essential amino acids like lysine
(D) Soluble dietary fibers

2012

62. Which classification applies to the major storage proteins of maize (zein), based on their insolubility in water but solubility in aqueous ethanol?
(A) Albumins
(B) Globulins
(C) Prolamins
(D) Glutelins

2019

63. The characteristic pungent aroma of members of the Brassicaceae family (e.g., mustard, cabbage) is released when physical damage mixes the enzyme myrosinase with which substrate?
(A) Anthocyanins
(B) Alliin
(C) Flavonoids
(D) Glucosinolates

2005

64. During the process of climacteric fruit ripening, which fundamental cellular change directly precedes the visible color transformation?
(A) Complete breakdown of the plasma membrane
(B) Lignification of the cell walls
(C) Conversion of chloroplasts into chromoplasts
(D) Synthesis of toxic secondary metabolites

2019

65. The post-harvest disorder known as "chilling injury" primarily occurs because low temperatures (above freezing) induce what biochemical change in sensitive produce?
(A) Complete cessation of cellular respiration
(B) Solidification of membrane lipids leading to loss of membrane semi-permeability
(C) Accelerated transcription of ethylene response factors
(D) Rapid crystallization of intracellular water

2010

66. The concept of "Agronomic Biofortification" fundamentally relies on which intervention?
(A) Using CRISPR-Cas9 to modify the crop genome
(B) Selective breeding of high-yielding crop varieties
(C) Addition of synthetic vitamins to milled flour
(D) Application of micronutrient-rich fertilizers to the soil or foliage

2012

67. Which specific class of polyphenolic compounds is responsible for the astringent taste in foods like unripe persimmons and green tea?
(A) Tannins
(B) Anthocyanidins
(C) Flavonols
(D) Coumarins

2005

68. The anti-nutritional impact of dietary oxalates is primarily driven by their ability to form highly insoluble complexes with which element?
(A) Iron
(B) Magnesium
(C) Calcium
(D) Zinc

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2022

69. Ergotism, a severe toxic condition caused by eating contaminated rye, is the result of which type of naturally occurring food toxin?
(A) Mycotoxins produced by Claviceps purpurea
(B) Endogenous plant alkaloids
(C) Bacterial enterotoxins
(D) Marine biotoxins

2024

70. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option:
Assertion (A) : Individuals with a genuine food allergy to peanuts must strictly avoid consuming any peanut proteins.
Reason (R) : Peanut allergens can trigger an IgE-mediated anaphylactic reaction, which can be rapidly fatal.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2015

71. Prebiotic dietary components primarily stimulate the growth and activity of which beneficial bacterial genera in the human colon?
(A) Bifidobacterium and Lactobacillus
(B) Escherichia and Salmonella
(C) Clostridium and Enterobacter
(D) Staphylococcus and Streptococcus

2007

72. Resveratrol, a powerful nutraceutical found in the skins of red grapes, belongs to which structural class of compounds?
(A) Isoflavones
(B) Carotenoids
(C) Stilbenes
(D) Terpenoids

2010

73. Which of the following functions best describes the primary use of butylated hydroxytoluene (BHT) as a synthetic food additive?
(A) Artificial coloring agent
(B) Emulsifier
(C) Antimicrobial preservative
(D) Antioxidant to prevent lipid rancidity

2010

74. In terms of energy calorimetry, what is the primary difference between the gross energy of a food (determined by bomb calorimetry) and its metabolizable energy?
(A) Metabolizable energy includes the thermal energy added during the cooking process
(B) Metabolizable energy is strictly the total energy utilized by the human brain
(C) Metabolizable energy subtracts energy lost in digestion, feces, and urine
(D) Gross energy only measures the energy content of the total carbohydrate fraction

2001

75. Which parameter plays the most critical role when calculating the Reference Body Weight for determining the RDA of a population?
(A) The highest recorded BMI in the population
(B) The mean weight of healthy adults in the specific age and gender group
(C) The ideal body weight required to achieve a BMI of 18.5
(D) The average weight of the top 10% athletic cohort

2019

76. Epimers are carbohydrates that differ only in the stereochemistry at a single chiral carbon. Which of the following are C-4 epimers?
(A) D-glucose and D-mannose
(B) D-mannose and D-fructose
(C) D-galactose and D-talose
(D) D-glucose and D-galactose

2009

77. Which physiological phenomenon provides the biochemical basis for the rapid reduction in postprandial blood glucose following the ingestion of low GI foods?
(A) Slower intestinal hydrolysis and steady glucose absorption
(B) Rapid hyperinsulinemia triggered by high sugar loads
(C) Immediate excretion of glucose by the kidney systems
(D) Direct conversion of carbohydrates into lipids in gut

2008

78. Insoluble dietary fibers, such as cellulose and lignin, exert their physiological benefits predominantly by:
(A) Slowing the transit time of chyme
(B) Binding to bile acids to lower cholesterol
(C) Increasing fecal bulk and promoting laxation
(D) Fermenting rapidly into methane gas

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(B) The presence of highly saturated carbon-carbon double bonds
(C) The hydroxyl groups that can donate hydrogen to free radicals
(D) The substitution of amine groups on the basic aromatic rings

2011

19. Phytic acid, an anti-nutritional factor in seeds, primarily exerts its negative physiological effect through which mechanism?
(A) Chelating divalent cations to reduce their intestinal bioavailability
(B) Inhibiting the action of pancreatic lipase enzymes in the duodenum
(C) Disrupting the lipid bilayer of enterocytes in the digestive tract
(D) Oxidizing ascorbic acid within the human gastrointestinal system

2011

20. Which endogenous food toxin, naturally found in sprouting potatoes, disrupts cell membranes and inhibits acetylcholinesterase?
(A) Gossypol
(B) Aflatoxin B1
(C) Lathyrogen
(D) Solanine

2018

21. The immunological mechanism underlying Celiac disease is triggered by the ingestion of which specific prolamins?
(A) Glycinins and conglycinins
(B) Gliadins and glutenins
(C) Zeins and kafirins
(D) Phaseolins and vicilins

2007

22. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option:
Assertion (A) : Regular consumption of probiotic bacteria significantly improves the human host's digestion of lactose.
Reason (R) : Probiotic bacteria secrete exogenous β-galactosidase in the gut, which hydrolyzes lactose into glucose and galactose.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2012

23. Plant sterols (phytosterols) are classified as functional food components primarily because they help prevent which condition?
(A) Osteoporosis
(B) Scurvy
(C) Iron-deficiency anemia
(D) Hypercholesterolemia

2013

24. Which of the following food additives is an artificial sweetener classified as GRAS but contains a warning for individuals with phenylketonuria?
(A) Aspartame
(B) Saccharin
(C) Sucralose
(D) Acesulfame potassium

2004

25. The basal metabolic rate (BMR) represents the minimal energy expended by an awake individual under controlled conditions. Which factor most directly correlates with a higher BMR?
(A) High proportion of adipose tissue
(B) High lean body mass (fat-free mass)
(C) Increased ambient temperature above the thermoneutral zone
(D) Advanced chronological age

2024

26. Which formulation parameter is typically NOT incorporated when establishing the Recommended Dietary Allowance (RDA) for a nutrient?
(A) The average daily requirement of the target population
(B) The individual's personal dietary preferences
(C) The standard deviation of the requirement within the population
(D) The coefficient of variation for the nutrient requirement

2008

27. Amylose and amylopectin differ significantly in their physicochemical characteristics. Which statement accurately compares them?
(A) Amylose forms helical structures that bind iodine for a blue color
(B) Amylose is highly branched, whereas amylopectin is exclusively linear
(C) Amylopectin has higher solubility in cold water than the amylose form
(D) Amylopectin contains only $\alpha(1_{\rightarrow}4)$ glycosidic bonds in its chain

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(A) Banana
(B) Citrus (e.g., Orange)
(C) Apple
(D) Tomato

2014

89. Controlled Atmosphere (CA) storage is extensively used to delay post-harvest deterioration. Which specific atmospheric modification is typically employed?
(A) Decreased O2 and increased CO2
(B) Increased O2 and decreased CO2
(C) Complete elimination of nitrogen gas
(D) Saturation with ethylene gas

2007

90. In the metabolic engineering of plants for biofortification, which pathway was modified to increase the production of folates (Vitamin B9) in food crops?
(A) The mevalonate pathway
(B) The Calvin cycle
(C) The citric acid cycle
(D) The shikimate and pteridine pathways

2002

91. The free-radical scavenging ability of anthocyanins is strongly dependent on the environmental pH. At which pH do anthocyanins typically exhibit their characteristic deep red flavylium cation structure?
(A) Highly acidic (pH < 3)
(B) Neutral (pH 7)
(C) Moderately alkaline (pH 8-9)
(D) Highly alkaline (pH > 10)

2003

92. Cyanogenic glycosides, such as linamarin found in cassava, become highly toxic anti-nutritional factors when they are enzymatically hydrolyzed to release which compound?
(A) Hydrogen peroxide
(B) Carbon monoxide
(C) Hydrogen cyanide
(D) Sulfur dioxide

2023

93. Marine biotoxins such as tetrodotoxin, an endogenous toxin in pufferfish, cause severe paralysis and death by which specific toxicodynamic mechanism?
(A) Inhibiting cytochrome c oxidase in mitochondria
(B) Depleting intracellular ATP via uncoupling of oxidative phosphorylation
(C) Hyperactivating muscarinic acetylcholine receptors
(D) Blocking voltage-gated sodium channels in nerve membranes

2018

94. Consider the following statements regarding food allergies and intolerances:
I. Food allergies always involve an immune system response, typically mediated by IgE.
II. Lactose intolerance is caused by the immune system mistakenly attacking milk proteins.
III. Celiac disease is an autoimmune condition triggered by the ingestion of gluten.
IV. Food intolerances can be entirely dose-dependent and non-immunological.
V. Anaphylaxis is a common symptom of severe metabolic food intolerances.
Which of the above statement(s) is/are correct?
(A) I, III and IV
(B) II, IV and V
(C) I, II and III
(D) I, IV and V

2018

95. The primary mechanism of action for most documented probiotic bacteria involves:
(A) Permanent colonization and replacement of the native microbiome
(B) Pathogen exclusion and modulation of intestinal immunity
(C) Complete digestion of all dietary insoluble fibers in the gut
(D) Systemic absorption into the blood to fight various infections

2005

96. Lycopene is classified as a potent nutraceutical. It is a non-provitamin A carotenoid recognized predominantly for its protective effects against which specific health condition?
(A) Night blindness
(B) Rickets
(C) Scurvy
(D) Prostate cancer

2002

97. Which natural food additive is a hydrocolloid derived from brown seaweeds, commonly used as a thickener and gelling agent in the presence of calcium ions?
(A) Sodium alginate
(B) Carrageenan
(C) Agar
(D) Guar gum

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(C) Cereals are high in methionine but low in lysine, while pulses are high in lysine but low in methionine.
(D) Pulses completely lack carbohydrates, balancing the high starch in cereals.

2024

159. In the Osborne classification system, albumins are defined as seed proteins that are:
(A) Soluble in pure water and coagulable by heat
(B) Soluble only in dilute salt solutions
(C) Soluble in 70-80% aqueous ethanol
(D) Soluble only in dilute acids or alkalis

2024

160. Which of the following correctly identifies the primary biochemical role of the pigment anthocyanin in commercial fruits?
(A) To perform photosynthesis
(B) To act as a structural component of the primary cell wall
(C) To synthesize essential fatty acids
(D) To provide water-soluble red, purple, or blue colors to attract seed dispersers

2022

161. The "climacteric peak" in fruit ripening refers strictly to a sudden, dramatic spike in the physiological rate of:
(A) Water transpiration
(B) Respiration and ethylene production
(C) Cell division (mitosis)
(D) Chlorophyll biosynthesis

2016

162. Controlled Atmosphere (CA) storage maintains fruit quality by significantly slowing respiration. Which enzymatic process is fundamentally restricted under reduced oxygen conditions in CA storage?
(A) Glycolysis
(B) Fermentation
(C) The action of cytochrome c oxidase in the mitochondrial electron transport chain
(D) DNA replication

2003

163. The primary focus of metabolic engineering for enhancing the nutritional profile of the cassava crop targets increasing the levels of:
(A) Iron, zinc, and provitamin A
(B) Cyanogenic glycosides and oxalates
(C) Essential fats and simple sugars
(D) Cellulose and lignin

2019

164. The free-radical scavenging mechanism of dietary antioxidants like Vitamin E (α-tocopherol) heavily relies on its ability to:
(A) Form covalent bonds with DNA to protect it from radiation
(B) Bind directly to transition metals preventing Fenton reactions
(C) Sequester molecular oxygen in the cytoplasm
(D) Donate a hydrogen atom to neutralize a lipid peroxyl radical

2001

165. The presence of phytic acid (myo-inositol hexakisphosphate) in a diet predominantly based on unrefined cereals primarily poses a risk for developing which specific deficiency?
(A) Vitamin C deficiency
(B) Iron and Zinc deficiency
(C) Essential fatty acid deficiency
(D) Iodine deficiency

2005

166. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option:
Assertion (A) : The consumption of raw kidney beans can cause severe acute gastroenteritis.
Reason (R) : Raw kidney beans contain high levels of phytohaemagglutinin (PHA), a toxic lectin that binds to the intestinal mucosa and disrupts enterocyte function.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2023

167. Food sensitivities often include adverse reactions to biogenic amines. Which biogenic amine, naturally found in aged cheeses and red wine, can cause hypertensive crises in individuals taking MAO inhibitor drugs?
(A) Tyramine
(B) Histamine
(C) Putrescine
(D) Cadaverine

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2012

168. To be rigorously classified as a "probiotic," a microbial strain must satisfy which fundamental criterion?
(A) It must be derived strictly from a plant source.

2015

109. Which of the following extrinsic dietary factors strongly inhibits the intestinal absorption of dietary zinc?
(A) Ascorbic acid
(B) Citric acid
(C) Simple sugars
(D) Phytic acid

2023

110. Among the following cereals, which one possesses the highest naturally occurring concentration of total proteins and lipids, concentrated heavily in its germ?
(A) Rice (Oryza sativa)
(B) Maize (Zea mays)
(C) Oat (Avena sativa)
(D) Sorghum (Sorghum bicolor)

2023

111. Legume storage proteins are primarily composed of two main fractions based on sedimentation coefficients. These are typically:
(A) 2S and 5S albumins
(B) 7S (vicilins) and 11S (legumins) globulins
(C) 15S and 20S prolamins
(D) 30S and 50S glutelins

2018

112. The specific volatile organic compound primarily responsible for the characteristic aroma of ripe bananas is:
(A) Cinnamaldehyde
(B) Diacetyl
(C) Isoamyl acetate
(D) Limonene

2009

113. In the biochemical pathway of ethylene biosynthesis, the immediate precursor that is directly oxidized to yield ethylene is:
(A) S-adenosylmethionine (SAM)
(B) Methionine
(C) Alpha-ketoglutarate
(D) 1-aminocyclopropane-1-carboxylic acid (ACC)

2004

114. Post-harvest browning in many fruits and vegetables, such as cut apples, is primarily catalyzed by the enzyme polyphenol oxidase (PPO) in the presence of:
(A) Molecular oxygen
(B) Molecular nitrogen
(C) Carbon dioxide
(D) Hydrogen gas

2004

115. A highly successful example of metabolic engineering for biofortification is the enrichment of tomato fruits with high levels of which potent antioxidant antioxidant anthocyanin?
(A) Quercetin
(B) Delphinidin
(C) Kaempferol
(D) Hesperidin

2009

116. Structurally, catechins and epicatechins found abundantly in tea leaves belong to which specific subclass of flavonoids?
(A) Flavanones
(B) Flavan-3-ols
(C) Flavonols
(D) Isoflavones

2003

117. Which anti-nutritional factor, prevalent in sorghum and some legumes, binds strongly to dietary proteins and digestive enzymes, precipitating them and drastically reducing protein digestibility?
(A) Condensed tannins
(B) Phytate
(C) Oxalate
(D) Glucosinolates

2019

118. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option:
Assertion (A) : Chronic consumption of Lathyrus sativus (grass pea) can lead to a severe neurodegenerative disorder called neurolathyrism.
Reason (R) : Grass pea contains the neurotoxin β-N-oxalyl-L- α,β-diaminopropionic acid (ODAP), which acts as an excitotoxin at glutamate receptors.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2005

119. In the context of food sensitivities, which biogenic amine is frequently implicated in pseudo-allergic reactions following the consumption of spoiled scombroid fish (e.g., tuna, mackerel)?
(A) Histamine
(B) Tyramine

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2013

178. Order the following forms of lipid deterioration from the fastest to the slowest expected rate of occurrence at room temperature in the dark:
I. Highly polyunsaturated oils (e.g., fish oil)
II. Monounsaturated oils (e.g., olive oil)
III. Fully saturated solid fats (e.g., fully hydrogenated lard)
(A) I, II, III
(B) II, I, III
(C) III, II, I
(D) I, III, II

2003

179. The omega-6 essential fatty acid linoleic acid is metabolically converted in the human body to arachidonic acid through a sequence of specific enzymatic steps. This sequence primarily involves:
(A) Hydroxylation and decarboxylation
(B) Desaturation and elongation
(C) Hydrogenation and esterification
(D) Oxidation and cleavage

2005

180. Which macro-mineral acts biochemically as the primary intracellular cation, regulating cell volume and maintaining the resting membrane potential?
(A) Sodium
(B) Potassium
(C) Calcium
(D) Chloride

2009

181. Intrinsic host factors such as advancing age frequently lead to atrophic gastritis. This condition drastically reduces the bioavailability of which specific nutrient due to the lack of stomach acid and intrinsic factor?
(A) Vitamin B12
(B) Vitamin C
(C) Glucose
(D) Short-chain fatty acids

2004

182. Which oilseed is distinctively recognized for containing exceptional levels of lignans (e.g., secoisolariciresinol diglucoside), a type of phytoestrogen and antioxidant?
(A) Sunflower seed
(B) Peanut
(C) Flaxseed (Linseed)
(D) Mustard seed

2013

183. Cereal prolamins are specifically characterized by their high concentration of the amino acid proline. What structural effect does a high proline content impart to these storage proteins?
(A) It induces the formation of perfectly straight alpha-helices.
(B) It causes the protein to heavily bind to calcium ions.
(C) It renders the protein completely soluble in cold water.
(D) It disrupts secondary structures creating kinked conformations.

2013

184. The flavor compound capsaicin, responsible for the pungency in chili peppers, is classified biochemically as an:
(A) Isothiocyanate
(B) Anthocyanin
(C) Alkaloid
(D) Ester

2024

185. During non-climacteric fruit ripening, which physiological parameter remains relatively stable and does NOT exhibit a sudden dramatic spike?
(A) Sugar accumulation
(B) Cellular respiration rate
(C) Pigment synthesis
(D) Acid degradation

2008

186. During post-harvest handling, "transpiration" is the primary physiological process responsible for:
(A) The synthesis of new aromatic compounds
(B) The conversion of starches into sugars
(C) The repair of mechanical injuries
(D) The continuous loss of water vapor from the fresh produce, leading to wilting

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2010

187. The application of metabolic engineering to produce "purple tomatoes" enriched their nutritional profile by significantly upregulating the biosynthesis of which specific compound class?
(A) Anthocyanins
(B) Carotenoids
(C) Essential amino acids
(D) Ascorbic acid

2017

188. Which class of plant polyphenols is fundamentally defined structurally by the presence of a gallic

II. Oxidative rancidity requires the presence of molecular oxygen and unsaturated fatty acids.
III. Ketonic rancidity is exclusively mediated by fungal metabolism of short-chain fatty acids.
IV. Hydrolytic rancidity always results in the formation of carcinogenic peroxides.

Which of the above statement(s) is/are INCORRECT?
(A) I, II and III
(B) I, III and IV
(C) Only IV
(D) II and IV

2022

131. In the context of essential fatty acids, what defines an "Omega-3" (n-3) fatty acid?
(A) It contains exactly three carbon atoms.
(B) It contains exactly three double bonds.
(C) The first double bond is at the third carbon from the carboxyl end.
(D) The first double bond is at the third carbon from the methyl end.

2025

132. Which essential trace element is a critical structural component of the antioxidant enzyme superoxide dismutase (SOD) found in the cytosol?
(A) Iron
(B) Copper (along with Zinc)
(C) Selenium
(D) Molybdenum

2013

133. The bioavailability of dietary macronutrients can be negatively impacted by intrinsic gastrointestinal factors. Which condition severely reduces dietary lipid absorption, leading to steatorrhea?
(A) Hyperchlorhydria
(B) Overproduction of salivary amylase
(C) Biliary obstruction preventing bile salt secretion
(D) Excessive secretion of intrinsic factor

2013

134. Which cereal grain is uniquely recognized for its high content of the soluble fiber β-glucan, which is clinically proven to lower serum LDL cholesterol?
(A) Wheat
(B) Rice
(C) Maize
(D) Barley

2002

135. The functional property of wheat flour that allows for the formation of viscoelastic dough required for bread making is solely attributed to:
(A) Interaction of gliadin and glutenin to form a gluten network
(B) The high concentration of starch granules found in the flour
(C) The presence of pentosans that absorb excess water in dough
(D) Rapid fermentation of native sugars by endogenous enzymes

2009

136. The biochemical degradation of ascorbic acid (Vitamin C) in fruits during prolonged storage is accelerated by:
(A) Low oxygen levels
(B) Darkness
(C) The presence of catalytic transition metals like copper and iron
(D) Freezing temperatures below -20°C

2004

137. Which phytohormone is generally recognized as a profound inhibitor of the ripening and senescence processes in fruits?
(A) Ethylene
(B) Cytokinin
(C) Brassinosteroid
(D) Jasmonic acid

2009

138. Which of the following is a key physiological rationale for coating the surface of fresh citrus fruits with food-grade waxes during post-harvest handling?
(A) To accelerate the respiratory rate and enhance flavor
(B) To promote the growth of beneficial surface molds
(C) To increase the absorption of ambient oxygen
(D) To reduce water loss (transpiration) and delay shrinkage

2003

139. Biofortification of crops with provitamin A (β -carotene) provides a biochemical precursor that the human body cleaves primarily using which enzyme in the intestinal mucosa?
(A) Retinal dehydrogenase
(B) Retinol-binding protein
(C) β,β-carotene 15,15'-monooxygenase
(D) Lipoxygenase

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2019

98. An individual's basal metabolic rate (BMR) can be most accurately mathematically estimated using which of the following standard predictive equations?
(A) Henderson-Hasselbalch equation
(B) Michaelis-Menten equation
(C) Harris-Benedict equation
(D) Nernst equation

2004

99. The formulation of Recommended Dietary Allowances (RDA) requires defining the Reference Man and Reference Woman. In the Indian context (ICMR-NIN 2020), the Reference Man's body weight has been revised to:
(A) 55 kg
(B) 60 kg
(C) 65 kg
(D) 70 kg

2006

100. Which physiochemical property of dietary carbohydrates prevents human digestive enzymes from hydrolyzing cellulose?
(A) The presence of exclusively $\alpha(1\rightarrow6)$ branches
(B) The highly cross-linked pentose sugar backbone
(C) The lack of free hydroxyl groups
(D) The specific configuration of $\beta(1\rightarrow4)$ linkages

2014

101. The Glycemic Index (GI) classifies foods containing carbohydrates. Which of the following foods is universally classified as having a high GI (≥ 70)?
(A) Lentils
(B) Plain boiled white rice
(C) Raw carrots
(D) Whole milk

2005

102. Which type of dietary fiber is primarily responsible for forming a viscous gel in the stomach, effectively delaying gastric emptying?
(A) Lignin
(B) Cellulose
(C) Pectin
(D) Chitin

2019

103. Which classification best applies to the dietary protein casein found in milk?
(A) Simple glycoprotein
(B) Derived metalloprotein
(C) Incomplete structural protein
(D) Conjugated phosphoprotein

2019

104. The Protein Digestibility Corrected Amino Acid Score (PDCAAS) is truncated at a maximum score of:
(A) 0.50
(B) 100.0
(C) 1.00
(D) 10.0

2001

105. During lipid autoxidation, the termination phase is characterized by which specific chemical event?
(A) The combination of two free radicals to form a stable, non-radical molecule
(B) The release of highly volatile hexanal
(C) The cleavage of the hydroperoxide intermediate
(D) The loss of an electron from a double bond

2021

106. Determine the correct sequential arrangement for the biochemical phases of lipid autoxidation:
I. Propagation
II. Termination
III. Initiation
IV. Hydroperoxide decomposition
(A) III, I, IV, II
(B) III, II, I, IV
(C) I, III, II, IV
(D) III, IV, I, II

2004

107. The essentiality of linoleic acid (Omega-6) and alpha-linolenic acid (Omega-3) in the human diet is due to the lack of specific enzymes required to insert double bonds beyond which carbon atom (counting from the carboxyl end)?
(A) Carbon 9
(B) Carbon 3
(C) Carbon 6
(D) Carbon 12

2010

108. Which specific macromineral functions structurally in the stabilization of ATP molecules and physiologically in neuromuscular transmission?
(A) Sodium
(B) Chloride
(C) Magnesium
(D) Iron

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molecular weight. Which characteristic strictly applies to simple sugars (monosaccharides) but NOT to complex polysaccharides like starch?
(A) The ability to undergo gelatinization
(B) The ability to form highly viscous pastes
(C) Sweetness and high solubility in cold water
(D) The capacity to provide 4 kcal of energy per gram

2011

150. A food that causes a slow, steady release of glucose into the bloodstream over several hours would be characterized biochemically as having:
(A) A low Glycemic Index
(B) A very high Glycemic Index
(C) Zero accessible calories
(D) A high proportion of easily digestible amylopectin

2014

151. Which statement best contrasts soluble and insoluble dietary fibers?
(A) Soluble fibers come from animal sources; insoluble fibers are plant-based
(B) Soluble fibers provide 9 kcal/g, while insoluble fibers provide 4 kcal/g
(C) Soluble fibers form gels and ferment; insoluble fibers act as bulk
(D) Soluble fibers speed up gastric emptying; insoluble fibers slow it down

2022

152. Dietary proteins function not only structurally but also in the maintenance of fluid balance. Which plasma protein is the primary regulator of intravascular oncotic pressure?
(A) Fibrinogen
(B) Globulin
(C) Hemoglobin
(D) Albumin

2024

153. In calculating the true digestibility of a protein, the mathematical formula explicitly accounts for which critical physiological factor that apparent digestibility ignores?
(A) Endogenous obligatory fecal nitrogen losses
(B) Urinary nitrogen output
(C) Total dietary fiber intake
(D) Intestinal transit time

2013

154. Consider the following statements regarding the functional properties of food lipids:
I. Lipids act as heat transfer media during deep-fat frying.
II. Lipids contribute to the aeration and flakiness in baked pastries.
III. Lipids naturally increase the caloric density of food formulations.
IV. Phospholipids, due to their amphiphilic nature, act as excellent food emulsifiers.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) II, III and IV
(C) I, II and III
(D) I and IV only

2018

155. The principal biochemical significance of consuming an optimal dietary ratio of Omega-6 to Omega-3 fatty acids is to:
(A) Maximize the synthesis of saturated fatty acids in the liver
(B) Balance the production of pro- and anti-inflammatory eicosanoids
(C) Completely suppress the activity of cyclooxygenase enzymes
(D) Ensure sufficient fat accumulation in adipose tissue

2021

156. Which macro-mineral is the principal extracellular cation vital for the maintenance of osmotic pressure and action potentials in the human body?
(A) Potassium
(B) Calcium
(C) Magnesium
(D) Sodium

2012

157. The intestinal absorption of fat-soluble vitamins (A, D, E, K) fundamentally requires the presence of which physiological factor in the intestinal lumen?
(A) Adequate micelle formation facilitated by dietary fats and bile salts
(B) High concentrations of intrinsic factor
(C) A highly acidic pH environment in the ileum
(D) Proteolytic enzymes to cleave the vitamin structures

2002

158. The protein nutritional profile of major cereals (e.g., wheat, rice) and pulses (e.g., beans, lentils) naturally complement each other because:
(A) Cereals are high in lysine but low in methionine, while pulses are high in methionine but low in lysine.
(B) Both are completely devoid of tryptophan.

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2012

140. Which specific class of polyphenolic compounds is uniquely abundant in soybeans and is widely studied for its weak estrogenic (phytoestrogen) activity?
(A) Isoflavones (e.g., genistein and daidzein)
(B) Anthocyanins
(C) Flavonols
(D) Hydroxycinnamic acids

2001

141. The anti-nutritional compound gossypol is a toxic polyphenolic pigment naturally found in which seed?
(A) Rapeseed
(B) Linseed
(C) Cottonseed
(D) Sesame seed

2009

142. Match the specific mycotoxin (List I) with its primary target organ for toxicity in humans or animals (List II).
List I : (Mycotoxin)
P. Aflatoxin B1
Q. Ochratoxin A
R. Zearalenone
S. Fumonisin B1
List II : (Target Organ)
1. Kidneys (Nephrotoxicity)
2. Liver (Hepatotoxicity)
3. Reproductive system (Estrogenic effects)
4. Nervous system / Esophagus (Leukoencephalomalacia / Cancer)
(A) P-2, Q-1, R-3, S-4
(B) P-1, Q-2, R-4, S-3
(C) P-2, Q-3, R-1, S-4
(D) P-3, Q-1, R-2, S-4

2024

143. In individuals suffering from celiac disease, the autoimmune response triggered by gluten results directly in which structural alteration in the gastrointestinal tract?
(A) Thickening of the esophageal lining
(B) Hyperplasia of the gastric rugae
(C) Deep ulceration of the colon
(D) Atrophy and flattening of the intestinal villi

2007

144. Which of the following statements best describes the biochemical nature of a "prebiotic"?
(A) A non-digestible ingredient that stimulates beneficial gut bacteria
(B) A live bacterial culture that provides immediate digestive relief
(C) A broad-spectrum antibiotic used to clear the gut for colonization
(D) An encapsulated digestive enzyme supplement used for health aid

2024

145. Nutraceuticals derived from marine sources, specifically fish oils, are biochemically important primarily because they provide abundant:
(A) Squalene and vitamin C
(B) Conjugated linoleic acid (CLA)
(C) Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)
(D) Astaxanthin and dietary fiber

2012

146. Monosodium glutamate (MSG) is a food additive commonly used worldwide for which specific functional purpose?
(A) To impart a savory, "umami" flavor enhancement
(B) To inhibit the growth of Clostridium botulinum
(C) To prevent the oxidative browning of cut fruits
(D) To artificially sweeten diet beverages

2014

147. Indirect calorimetry measures the Basal Metabolic Rate (BMR) by quantifying:
(A) The exact amount of heat radiating from the skin surface
(B) The total volume of oxygen consumed and carbon dioxide produced
(C) The amount of urea excreted in a 24-hour urine sample
(D) The change in core body temperature over one hour

2019

148. Which parameter is used to adjust the generic Recommended Dietary Allowance (RDA) values for pregnant women?
(A) Subtraction of energy costs associated with menstruation
(B) Multiplication of the base RDA by the mother's exact chronological age
(C) No adjustment is made; RDA remains constant regardless of physiological state
(D) Addition of energy and nutrient costs required for fetal growth and maternal tissue expansion

2025

149. Carbohydrates typically exhibit diverse physicochemical characteristics based on their

NODIA

(B) It must be capable of causing a mild, self-limiting infection to stimulate immunity.
(C) It must be administered alive in adequate amounts to confer a health benefit to the host.
(D) It must completely eradicate all native gut microflora.

2013

169. Plant stanol esters are actively added to certain commercial margarines to capitalize on their ability to:
(A) Prevent the oxidation of the margarine during storage
(B) Enhance the absorption of fat-soluble vitamins
(C) Substitute the caloric value of regular fats completely
(D) Lower serum LDL cholesterol levels

2011

170. Which natural food additive is an organic acid widely used as an acidulant, chelating agent, and flavor enhancer, particularly in carbonated beverages?
(A) Ascorbic acid
(B) Acetic acid
(C) Citric acid
(D) Propionic acid

2015

171. In classical energy calorimetry, what is the standardized physiological energy value (Atwater general factor) for digestible dietary carbohydrates?
(A) 2 kcal/g
(B) 4 kcal/g
(C) 7 kcal/g
(D) 9 kcal/g

2025

172. According to optimal dietary guidelines, what percentage of total daily energy should ideally come from complex carbohydrates?
(A) 10 - 20%
(B) 25 - 35%
(C) 50 - 60%
(D) 75 - 85%

2013

173. The physicochemical characteristic of carbohydrates known as "mutarotation" refers to:
(A) The spontaneous interconversion between the α and β anomeric forms of a sugar in aqueous solution
(B) The physical spinning of the sugar crystal under polarized light
(C) The hydrolysis of a disaccharide into monosaccharides
(D) The browning of sugar when heated above its melting point

2001

174. Which of the following best defines the specific physiological significance of a low Glycemic Index (GI) diet over a long-term period?
(A) Rapid replenishment of muscle glycogen post-exercise
(B) Immediate enhancement of aerobic cardiovascular capacity
(C) Reduced insulin demand and a lower risk of Type 2 diabetes
(D) Accelerated catabolism of muscle protein in active adults

2025

175. The physiological health impact of consuming highly fermentable soluble dietary fiber is largely mediated by the production of short-chain fatty acids (SCFAs). Which SCFA is the primary energy source for human colonocytes?
(A) Butyrate
(B) Acetate
(C) Propionate
(D) Valerate

2011

176. Which classification of dietary proteins is applied strictly to proteins that have been partially degraded by physical or enzymatic processes?
(A) Simple proteins
(B) Secondary derived proteins
(C) Conjugated proteins
(D) Primary derived proteins

2012

177. The Protein Digestibility Corrected Amino Acid Score (PDCAAS) evaluates protein quality. Which of the following factors specifically limits the score of plant-based proteins compared to animal proteins?
(A) Extremely low total nitrogen content found in plants
(B) The absence of all non-essential amino acids in veg
(C) The inability of plant proteins to form structures
(D) Lower digestibility and limiting essential amino acids

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(C) Serotonin
(D) Dopamine

2010

120. Which compound is a well-characterized prebiotic strictly composed of fructose polymers?
(A) Xylooligosaccharide (XOS)
(B) Galactooligosaccharide (GOS)
(C) Fructooligosaccharide (FOS)
(D) Resistant starch

2004

121. Plant-derived functional foods containing significant amounts of sterols and stanols exert their cholesterol-lowering effect by:
(A) Inhibiting the absorption of cholesterol in the small intestine
(B) Directly degrading cholesterol present within the bloodstream
(C) Blocking the endogenous synthesis of cholesterol in the liver
(D) Binding to bile acids to form insoluble complexes in the colon

2009

122. Which food additive classification accurately describes the function of sodium nitrite in processed meats?
(A) Emulsifier and stabilizing agent
(B) Antimicrobial agent and color fixative
(C) Artificial flavor enhancer
(D) Anti-caking agent

2003

123. The energy required to raise the temperature of 1 gram of water by 1 degree Celsius is defined as one:
(A) Joule
(B) Watt
(C) Erg
(D) Calorie

2004

124. When calculating the Recommended Dietary Allowance (RDA) for protein, the FAO/WHO recommends an adult intake of approximately:
(A) 0.50 g / kg body weight / day
(B) 0.83 g / kg body weight / day
(C) 1.50 g / kg body weight / day
(D) 2.00 g / kg body weight / day

2013

125. The Maillard reaction is a non-enzymatic browning process that occurs primarily between which two components?
(A) Two reducing sugar molecules
(B) A saturated fatty acid and an oxygen molecule
(C) A reducing sugar and a free amino group of a protein
(D) A polyphenol and an organic acid

2013

126. Which structural parameter primarily dictates whether a starch is rapidly digestible, slowly digestible, or resistant?
(A) The exact number of carbon atoms in the glucose monomers
(B) The color of the starch granule
(C) The presence of essential amino acids within the starch matrix
(D) The degree of crystallization and the proportion of amylose to amylopectin

2018

127. The physiological health impacts of insoluble dietary fibers are most closely associated with the prevention of which condition?
(A) Constipation and diverticular disease
(B) Type 1 Diabetes
(C) Hyperthyroidism
(D) Essential hypertension

2005

128. In terms of protein functional properties, the ability of a protein to form stable foams (e.g., egg white albumin in meringues) is fundamentally dependent on its ability to:
(A) Completely resist thermal denaturation
(B) Hydrolyze into constituent dipeptides rapidly
(C) Adsorb at the air-water interface to form a viscoelastic film
(D) Cross-link specifically with metallic ions

2003

129. The Biological Value (BV) of a protein measures:
(A) The percentage of true absorbed nitrogen that is retained by the body
(B) The ratio of essential to non-essential amino acids
(C) The total energy provided by one gram of the protein
(D) The weight of the protein relative to its volume

2005

130. Consider the following statements regarding types of lipid rancidity and their primary causes:
I. Hydrolytic rancidity is caused by the enzymatic cleavage of triglycerides by lipases.

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acid derivative esterified to a central glucose core?
(A) Condensed tannins
(B) Flavanones
(C) Hydrolyzable tannins
(D) Lignans

2008

189. Protease inhibitors present in raw pulses act as anti-nutritional factors by binding strictly to, and inhibiting the function of, which key digestive enzymes?
(A) Trypsin and chymotrypsin
(B) Amylase and lipase
(C) Pepsin and gastric lipase
(D) Lactase and sucrase

2015

190. Consider the following statements regarding mycotoxins in food commodities:
I. Mycotoxins are volatile organic compounds responsible for mold aroma.
II. Aflatoxins are primarily produced by Aspergillus flavus and parasiticus in hot, humid storage conditions.
III. Mycotoxins are completely destroyed by mild pasteurization (72°C for 15 seconds).
IV. Patulin is a common mycotoxin found in moldy apples and apple juices.
V. Chronic exposure to certain mycotoxins is strongly linked to hepatocellular carcinoma.
Which of the above statement(s) is/are correct?
(A) II, IV and V
(B) I, II and IV
(C) II, III and V
(D) I, III and IV

2012

191. An IgE-mediated food allergy involves a sensitization phase followed by an elicitation phase. During the elicitation phase upon re-exposure, the allergen directly cross-links IgE antibodies on the surface of which immune cells, causing degranulation?
(A) Mast cells and basophils
(B) Erythrocytes and platelets
(C) T-lymphocytes and B-lymphocytes
(D) Neutrophils and macrophages

2021

192. Prebiotics must endure the harsh environment of the upper gastrointestinal tract to reach the colon. Which fundamental structural property allows inulin to survive human digestive enzymes?
(A) It consists solely of perfectly linear alpha(1-4) linked glucose units.
(B) It is heavily esterified with hydrophobic long-chain fatty acids.
(C) Human enzymes cannot cleave its specific β $(2_{\rightarrow}1)$ linkages.
(D) It is shielded by a protective lignified outer sheath in the gut.

2008

193. Functional foods enriched with "phytostanols" differ chemically from "phytosterols" strictly by:
(A) Being fully saturated in the sterol ring (lacking double bonds)
(B) Having a higher number of double bonds in the ring structure
(C) Containing an esterified amino acid group
(D) Being derived exclusively from marine algae rather than terrestrial plants

2012

194. Sodium benzoate is widely used as a synthetic food additive primarily to inhibit the growth of:
(A) Spore-forming anaerobic bacteria
(B) Coliforms in alkaline foods
(C) Lactic acid bacteria in fermented milk products
(D) Yeasts and molds in acidic foods ($pH < 4.5$)

NODIA

2005

195. Approximately what percentage of the energy value of ingested protein is dissipated as heat during its processing (Specific Dynamic Action)?
(A) 2 - 5%
(B) 5 - 10%
(C) 20 - 30%
(D) 50 - 60%

2022

196. When formulating Recommended Dietary Allowances (RDA), why is an additional margin of safety added to the Estimated Average Requirement (EAR)?
(A) To account for individuals with massive hypermetabolic disorders
(B) To purposely encourage overconsumption of various micronutrients
(C) To cover the needs of 97.5% of the specific healthy population
(D) To adjust for energy losses solely during extreme physical effort

2003

197. Which structural classification defines the unique dietary carbohydrate "chitin"?
(A) A homopolymer of N-acetylglucosamine linked by $\beta(1_{\rightarrow}4)$ bonds

transporter and osmosis
(C) Endocytosis via clathrin-coated pits exclusively
(D) Passive paracellular diffusion and an active transcellular pathway via TRPM6/7 channels

2011

278. Which of the following physiological states is associated with a "negative nitrogen balance"?
(A) Childhood growth and development
(B) Recovery from a serious injury or infection
(C) Severe burns or prolonged starvation
(D) Pregnancy during the second trimester

2009

279. The structural classification of the legume seed storage protein "legumin" categorizes it as a:
(A) Simple water-soluble albumin
(B) Alcohol-soluble monomeric prolamin
(C) Insoluble complex lipoprotein
(D) Salt-soluble 11S globulin with disulfide bonds

2001

280. The volatile flavor compound "eugenol" provides the characteristic strong aroma to which specific commercial spice?
(A) Vanilla
(B) Cinnamon
(C) Clove
(D) Saffron

2021

281. The immediate final step in ethylene biosynthesis—the oxidation of ACC to ethylene—is catalyzed by:
(A) ACC oxidase
(B) Pectinase
(C) ACC synthase
(D) Lipoxygenase

2009

282. Post-harvest biochemical alterations in climacteric fruits include a sudden burst in respiration coinciding with the rapid production of:
(A) Abscisic acid
(B) Gibberellins
(C) Ethylene
(D) Auxin

2017

283. Metabolic engineering using RNA interference (RNAi) achieves trait modification in crops by:
(A) Inserting an entirely new bacterial gene to overproduce a nutrient
(B) Duplicating the entire plant genome to improve the nutritional yield
(C) Randomly mutating mitochondrial DNA to change phenotypic expressions
(D) Silencing a specific target gene that degrades a desired compound

2023

284. Structurally, "quercetin" belongs to which specific subclass of the flavonoid family?
(A) Flavonols
(B) Anthocyanidins
(C) Flavanones
(D) Isoflavones

2007

285. The thermal treatment (cooking) of raw legumes specifically denatures which class of anti-nutritional factors?
(A) Mineral oxalates
(B) Phytic acid
(C) Proteinaceous protease inhibitors and lectins
(D) Phenolic tannins

2003

286. "Ochratoxin A," found in improperly stored cereals and coffee, exerts its most severe toxicity on which organ system?
(A) The renal system (kidneys)
(B) The central nervous system
(C) The cardiovascular system
(D) The skeletal system

2009

287. Lactose intolerance occurs due to a biochemical deficiency in which specific intestinal enzyme?
(A) Maltase
(B) Lactase-phlorizin hydrolase
(C) Sucrase-isomaltase
(D) Alpha-dextrinase

2011

288. Which short-chain fatty acid (SCFA) is produced in the largest molar proportion during healthy colonic fermentation?
(A) Propionate
(B) Butyrate
(C) Acetate
(D) Valerate

2001

289. Conjugated linoleic acid (CLA) has been researched for its potential physiological benefit in:
(A) Curing type 1 diabetes

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(B) Lentil (Lens culinaris)
(C) Soybean (Glycine max)
(D) Pigeon pea (Pajanus cajan)

2024

207. According to Osborne's solubility classification, cereal storage proteins are primarily composed of prolamins and glutelins. Which specific solvent is required to selectively extract glutelins?
(A) Dilute acid or alkali solutions
(B) Distilled water
(C) Dilute saline solutions
(D) 70% aqueous ethanol

2014

208. The distinct flavor of onions is determined by a group of secondary metabolites. Which enzyme acts upon the odorless precursors (alk(en) yl cysteine sulfoxides) to produce the volatile agents upon cutting the tissue?
(A) Myrosinase
(B) Alliinase
(C) Lipoxygenase
(D) Polyphenol oxidase

2008

209. Ethylene biosynthesis during climacteric fruit ripening involves a key regulatory enzyme that converts SAM to ACC. This enzyme is known as:
(A) ACC oxidase
(B) Phenylalanine ammonia-lyase (PAL)
(C) ACC synthase
(D) Polygalacturonase

2014

210. Which primary biochemical change characterizes the senescence phase in vegetables post-harvest, leading directly to a loss of nutritional quality?
(A) Massive accumulation of starch
(B) Synthesis of new chlorophyll molecules
(C) Immediate conversion of complex carbohydrates into insoluble lignin
(D) Extensive degradation of cellular proteins and destruction of cellular compartmentalization

2002

211. A highly successful transgenic approach to combat iron deficiency in rice involves expressing which specific iron-storage protein in the rice endosperm?
(A) Ferritin
(B) Hemoglobin
(C) Transferrin
(D) Cytochrome c

2013

212. Flavonoids represent a major class of dietary antioxidants. The basic C6-C3-C6 flavonoid skeleton is naturally biosynthesized in plants through the convergence of which two metabolic pathways?
(A) Glycolysis and the citric acid cycle
(B) The shikimate and acetate-malonate pathways
(C) The pentose phosphate pathway and urea cycle
(D) The Calvin cycle and the mevalonate pathway

2015

213. Tannins exert their anti-nutritional effects primarily through their high binding affinity for dietary proteins. This binding is driven fundamentally by:
(A) Covalent disulfide bond formation
(B) Ionic bonding between positively charged tannins and negative amino acids
(C) Strong hydrogen bonding and hydrophobic interactions
(D) The specific cleavage of peptide bonds by the tannins

2015

214. In the following question, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct option:
Assertion (A) : The consumption of cassava (tapioca) that has been inadequately processed can result in acute cyanide poisoning.
Reason (R) : Cassava roots contain the cyanogenic glycosides linamarin and lotaustralin, which upon cellular damage are enzymatically hydrolyzed to release toxic hydrogen cyanide gas.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

NODIA

2024

215. In terms of immunological food sensitivities, what fundamentally distinguishes a true food allergy from a food intolerance?
(A) Allergies involve an immune response; intolerances are non-immunological
(B) A true allergy is dose-dependent, whereas intolerance is strictly trace
(C) A true allergy is strictly gut-mediated, whereas intolerance is systemic

(B) A heteropolymer of glucose and galactose
(C) A highly branched polymer of fructose
(D) A linear polymer of glucuronic acid

2018

198. The biochemical basis of a low Glycemic Index (GI) food often involves the physical entrapment of starch granules. In which of the following forms would the starch have the LOWEST GI?
(A) Finely milled, highly gelatinized wheat flour
(B) Chemically pre-digested maltodextrin
(C) Pure glucose powder
(D) Intact, ungelatinized starch granules encased within whole cereal grains

2009

199. Soluble dietary fibers physically alter the properties of gastrointestinal contents. Their capacity to lower serum cholesterol is directly tied to their ability to:
(A) Bind bile acids to prevent recirculation and force new synthesis
(B) Synthesize high-density lipoproteins (HDL) in the body system
(C) Completely inhibit the secretion of the pancreatic lipase enzyme
(D) Oxidize circulating LDL cholesterol particles in the bloodstream

2018

200. In protein biochemistry, which essential amino acid uniquely possesses an aromatic indole ring in its side chain?
(A) Phenylalanine
(B) Tryptophan
(C) Tyrosine
(D) Histidine

2021

201. The Digestible Indispensable Amino Acid Score (DIAAS) is currently the FAO-recommended method for protein quality evaluation. What is its principal methodological advantage over PDCAAS?
(A) It measures digestibility at the terminal ileum to avoid colonic interference
(B) It measures total nitrogen excretion rather than specific amino acid levels
(C) It uses a single universal reference pattern for all different age groups
(D) It inherently accounts for the exact thermal processing history of the food

2018

202. Match the lipid degradation phenomenon (List I) with its defining primary mechanism (List II).

List I : (Phenomenon)
P. Autoxidation
Q. Hydrolytic rancidity
R. Photo-oxidation
S. Thermal polymerization

List II : (Mechanism)
1. Free radical chain reaction initiated by heat/metals
2. Excitation of molecular oxygen to singlet oxygen by light and sensitizers
3. Cleavage of ester bonds by water and lipases
4. Cross-linking of fatty acid chains at frying temperatures

(A) P-1, Q-3, R-2, S-4
(B) P-2, Q-4, R-1, S-3
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-2, R-3, S-4

2007

203. Which specific fatty acid is classified structurally as an 18:2(n-6) essential fatty acid?
(A) Oleic acid
(B) Alpha-linolenic acid
(C) Linoleic acid
(D) Stearic acid

2015

204. What is the primary physiological function of the trace element fluoride in the human body?
(A) Acting as a structural component of the thyroid hormone
(B) Serving as an essential cofactor for RNA polymerase
(C) Regulating the body's iron storage capacity
(D) Promoting the conversion of hydroxyapatite to the harder, more decay-resistant fluorapatite in bones and teeth

2009

205. The bioavailability of dietary macronutrients such as proteins is drastically reduced by the intrinsic disorder known as achlorhydria, which specifically denotes the inability of the stomach to secrete:
(A) Hydrochloric acid
(B) Pepsinogen
(C) Gastrin
(D) Bicarbonate

2012

206. Which pulse crop is globally recognized for containing the highest concentration of total proteins (approximately 36-40% on a dry weight basis)?
(A) Chickpea (Cicer arietinum)

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(A) 0
(B) 50
(C) 100
(D) 1000

2014

226. Consider the following statements regarding the chemical structure of fatty acids:
I. Palmitic acid is a 16-carbon saturated fatty acid.
II. Oleic acid possesses a single trans double bond.
III. Eicosapentaenoic acid (EPA) is a 20-carbon fatty acid with 5 double bonds.
Which of the above statement(s) is/are correct?
(A) I and II only
(B) II and III only
(C) I and III only
(D) I, II and III

2022

227. In essential fatty acid metabolism, alpha-linolenic acid competes directly with linoleic acid for access to which critical, rate-limiting enzyme?
(A) Cyclooxygenase
(B) Lipoprotein lipase
(C) Delta-6 desaturase
(D) Acetyl-CoA carboxylase

2022

228. Which dietary compound class acts as a potent "goitrogen" by competitively inhibiting iodine uptake in the thyroid gland?
(A) Plant flavanols
(B) Dietary phytates
(C) Mineral oxalates
(D) Glucosinolates

2018

229. Natural food folates are predominantly in polyglutamated form and must be enzymatically cleaved prior to absorption into what form?
(A) Monoglutamates
(B) Free folic acid
(C) Pteridine rings
(D) Para-aminobenzoic acid (PABA)

2002

230. The nutritional profile of quinoa (Chenopodium quinoa) is highly regarded because, unlike most cereals, it provides:
(A) Exceptionally high levels of Vitamin B_{12}
(B) Complete lack of any complex carbohydrates
(C) Optimal balance of all essential amino acids
(D) High concentrations of toxic heavy metals

NODIA

2021

231. The molecular structure of the legume storage protein "vicilin" typically exists primarily as a:
(A) Monomer
(B) Hexamer (11S complex)
(C) Endless polymeric chain
(D) Trimer (7S complex)

2011

232. Which tropical fruit is notable for storing high levels of lipids in its mesocarp instead of simple sugars?
(A) Mango
(B) Avocado
(C) Papaya
(D) Pineapple

2011

233. Which enzyme acts first during fruit ripening to demethoxylate pectin chains, rendering them susceptible to further depolymerization?
(A) Polygalacturonase
(B) Cellulase
(C) Pectin methylesterase
(D) Xylanase

2025

234. During the post-harvest storage of fresh vegetables, internal heat generated by high respiration rates is known as:
(A) Specific dynamic action
(B) Sensible heat
(C) Latent heat of vaporization
(D) Vital heat

2011

235. Biofortified pearl millet varieties developed under the "HarvestPlus" initiative were primarily bred to accumulate high endosperm concentrations of:
(A) Iron and Zinc
(B) Provitamin A
(C) Vitamin C
(D) Omega-3 fatty acids

2016

236. Which reactive oxygen species (ROS) is a highly reactive non-radical species effectively neutralized by carotenoids through physical quenching?
(A) Hydroxyl radical ($^{\bullet}OH$)
(B) Superoxide anion ($O2^{\bullet}$-)
(C) Singlet oxygen ($_1O_2$)
(D) Hydrogen peroxide (H_2O_2)

(C) Structural proteins in the cell wall
(D) DNA sequences in the nucleus directly

2002

258. Chilling injury in tropical fruits is biochemically associated with:
(A) Immediate boiling of intracellular fluid
(B) Spontaneous combustion of essential oils
(C) Phase transition of membrane lipids from a fluid liquid-crystalline state to a solid gel state
(D) Complete inversion of sucrose into glucose and fructose

2004

259. A primary strategy in the metabolic engineering of "Golden Rice" required the introduction of the gene coding for:
(A) ACC oxidase
(B) Amylase
(C) Polygalacturonase
(D) Phytoene synthase

2024

260. Which of the following structural features in phenolic compounds is associated with the highest antioxidant activity?
(A) Ortho-diphenolic structures that stabilize unpaired electrons
(B) A single isolated hydroxyl group on a fully saturated ring
(C) Only methoxy substitutions and no free hydroxyl groups
(D) Long aliphatic saturated chains in the basic structure

2018

261. Protease inhibitors in raw soybeans are classified into two main families. The Kunitz inhibitor specifically targets which digestive enzyme?
(A) Pepsin
(B) Gastric lipase
(C) Trypsin
(D) Amylase

2017

262. Match the specific anti-nutritional factor or toxin (List I) with its corresponding primary biochemical mode of action (List II).
List I : (Factor)
P. Phytic acid
Q. Trypsin inhibitors
R. Haemagglutinins (Lectins)
S. Cyanogenic glycosides
List II : (Mode of Action)
1. Bind to intestinal epithelial cells and disrupt nutrient absorption
2. Strongly chelate divalent essential minerals
3. Inhibit specific pancreatic proteolytic enzymes
4. Inhibit cytochrome c oxidase upon degradation
(A) P-2, Q-3, R-1, S-4
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-4, R-1, S-3

2021

263. Celiac disease involves an adaptive immune response that targets tissue transglutaminase (tTG), an enzyme that modifies gluten peptides by converting:
(A) Lysine into arginine
(B) Proline into hydroxyproline
(C) Serine into glycine
(D) Glutamine into glutamic acid

2005

264. To achieve its health benefit, a "prebiotic" must remain undigested in the upper gastrointestinal tract. This resistance is due to the lack of human enzymes capable of hydrolyzing:
(A) β-glycosidic bonds (e.g., β(2→1) in inulin)
(B) α(1→4) glycosidic bonds
(C) Peptide bonds between amino acids
(D) Ester bonds in triglycerides

2014

265. Which of the following nutraceuticals is structurally classified as a plant sterol known to selectively inhibit cholesterol absorption?
(A) Ergocalciferol
(B) Beta-sitosterol
(C) Cholecalciferol
(D) Squalene

2006

266. The food additive "propionic acid" (and its salts) is predominantly used in baked goods to specifically inhibit the growth of:
(A) Pathogenic bacteria in canned meats
(B) Yeasts in fruit juices
(C) Molds in baked bakery goods (e.g., bread)
(D) Oxidative degradation in deep-frying oils

2025

267. Which specific organ or tissue contributes the highest total percentage of the daily resting energy expenditure in a healthy adult?
(A) Skeletal muscle (at rest)
(B) Adipose tissue
(C) The skin

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exceptional structural rigidity to plant cell walls but is totally indigestible?
(A) Pectin
(B) Cellulose
(C) Lignin
(D) Hemicellulose

2007

248. Which essential trace element is rigidly complexed within the porphyrin ring of the metalloprotein myoglobin?
(A) Magnesium
(B) Copper (Cu^{2+})
(C) Zinc (Zn^{2+})
(D) Iron (Fe^{2+})

2012

249. Which method for evaluating protein nutritional quality assesses the weight gain of a growing animal per gram of protein consumed?
(A) Protein Efficiency Ratio (PER)
(B) Net Protein Utilization (NPU)
(C) Biological Value (BV)
(D) Digestible Indispensable Amino Acid Score (DIAAS)

2002

250. Consider the following statements regarding the chemistry of food lipids and rancidity:
I. Lipoxygenases naturally present in raw beans strictly catalyze the oxidative degradation of unsaturated fatty acids.
II. Free transition metals actively lower the activation energy required for the initiation of lipid autoxidation.
III. Saponification is the basic hydrolysis of a triglyceride into glycerol and fatty acid salts.
IV. Antioxidants like Vitamin E effectively delay oxidative rancidity by donating hydrogen atoms to peroxy radicals.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and IV
(C) I, III and IV
(D) I, II and IV

2007

251. The "omega" nomenclature of fatty acids designates the position of the first double bond by counting carbon atoms from which specific group?
(A) The carboxyl group (-COOH)
(B) The hydroxyl group (-OH)
(C) The alpha carbon
(D) The methyl group ($-CH_3$)

2025

252. Which essential macro-mineral acts as a vital structural component of bones and teeth while serving as a secondary messenger in cellular signal transduction?
(A) Magnesium
(B) Calcium
(C) Phosphorus
(D) Sodium

2006

253. The bioavailability of dietary heme iron differs from non-heme iron because heme iron is absorbed by enterocytes via:
(A) The divalent metal transporter 1 (DMT1)
(B) Passive paracellular diffusion
(C) A specific intact metalloporphyrin transporter (HCP1)
(D) Endocytosis exclusively mediated by intrinsic factor

2007

254. The raw consumption of pulses is limited due to the presence of:
(A) Excessively high levels of saturated fats
(B) A complete lack of complex carbohydrates
(C) High concentrations of toxic heavy metals
(D) Endogenous anti-nutritional factors like trypsin inhibitors and lectins

2012

255. In cereal biochemistry, "prolamins" are the major storage proteins in most grains. However, oats are an exception; their major storage protein fraction is:
(A) Globulins
(B) Albumins
(C) Glutelins
(D) Histones

2005

256. Which secondary metabolite is a carotenoid responsible for the vibrant yellow-orange color of carrots and serves as a major provitamin A precursor?
(A) Lycopene
(B) Lutein
(C) β-carotene
(D) Astaxanthin

2018

257. At the biochemical level, ethylene initiates climacteric fruit ripening by binding to:
(A) Soluble enzymes in the cytoplasm
(B) Transmembrane receptors located on the endoplasmic reticulum

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(D) A true allergy is curable with antibiotics, whereas intolerance is fixed

2012

216. Which of the following physiological effects is NOT considered a direct health impact of consuming established probiotic strains?
(A) Modulation of the mucosal immune system
(B) Enhancement of the epithelial barrier function
(C) Competitive exclusion of pathogenic enteric bacteria
(D) Complete synthesis of the body's daily requirement of Vitamin B12

2010

217. Lycopene exhibits which specific physicochemical property due to its entirely hydrocarbon nature?
(A) Extreme solubility in cold water
(B) High solubility in lipids and organic solvents
(C) Rapid vaporization at room temperature
(D) Total resistance to photo-oxidation

2001

218. Food additive regulations classify "tartrazine" (FD&C Yellow 5) as a strictly regulated synthetic colorant because it is known to biochemically trigger:
(A) Severe acute hepatic failure
(B) The irreversible denaturation of all digestive enzymes
(C) The immediate precipitation of calcium in the bloodstream
(D) Hypersensitivity reactions and hyperactivity in children

2009

219. The basal metabolic rate (BMR) of an individual is significantly influenced by the circulating levels of which specific hormone?
(A) Thyroxine (T4)
(B) Insulin
(C) Glucagon
(D) Parathyroid hormone (PTH)

2006

220. The Recommended Dietary Allowance (RDA) for energy (caloric intake) differs from the RDA for micronutrients because the RDA for energy is set at:
(A) The absolute maximum level tolerated by a human
(B) The 97.5th percentile of the population's requirement
(C) The exact average (mean) requirement of the population group
(D) A uniform value of 2000 kcal for all age groups

2021

221. Structural classification of food carbohydrates differentiates oligosaccharides from polysaccharides based on their degree of polymerization (DP). Typically, an oligosaccharide is defined as having a DP between:
(A) 2 and 10 monosaccharide units
(B) 11 and 50 monosaccharide units
(C) 50 and 100 monosaccharide units
(D) Over 100 monosaccharide units

2004

222. The Glycemic Index (GI) of a food is evaluated by comparing the postprandial blood glucose area under the curve (AUC) of a test food to a reference food. Which substance is the universally accepted standard reference with a defined GI of 100?
(A) Pure glucose
(B) Pure fructose
(C) Pure sucrose
(D) White bread

2025

223. The physicochemical property of high-methoxyl pectin that allows it to form a rigid three-dimensional gel requires the presence of which two environmental conditions?
(A) High pH (alkaline) and high concentration of calcium ions
(B) High protein concentration and low sugar content in the mix
(C) Neutral pH and absence of any dissolved solids or additives
(D) Low pH and high concentration of sucrose (greater than 55%)

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2023

224. Which functional role is primarily fulfilled by dietary structural proteins, specifically collagen, upon its partial thermal hydrolysis into gelatin?
(A) Reversible oxygen binding
(B) Thermoreversible gelation and providing elasticity in food products
(C) Acting as an enzymatic catalyst
(D) Transporting essential fatty acids

2003

225. If a protein is perfectly digested and completely utilized for tissue synthesis without any urinary nitrogen loss, its theoretical Biological Value (BV) is:

(D) The liver

2023

268. The calculation "RDA = EAR + 2 Standard Deviations" mathematically ensures the RDA covers what percentage of the population?
(A) 50%
(B) 97.5%
(C) 68%
(D) 95%

2009

269. Glycogen differs structurally from amylopectin by:
(A) Containing strictly $\beta(1\rightarrow4)$ linkages
(B) Having completely unbranched linear polymer chains
(C) Being highly branched with $\alpha(1\rightarrow6)$ every 8-12 units
(D) Containing high amounts of nitrogen in its backbone

2013

270. Which physical factor related to the food matrix most dramatically reduces the Glycemic Index (GI) of a starchy food?
(A) High levels of intact dietary fiber and cellular structures
(B) Extensive mechanical milling into fine powder
(C) Prolonged thermal processing to fully gelatinize the starch
(D) Extrusion cooking under high pressure

2021

271. Soluble dietary fibers (e.g., gums and mucilages) significantly alter physiological health impacts by increasing the viscosity of the intestinal contents. This increased viscosity directly causes a reduction in:
(A) The total volume of feces produced
(B) The synthesis of short-chain fatty acids
(C) The overall transit time of chyme through the entire colon
(D) The rate of nutrient absorption in the gut system

2019

272. Dietary proteins fulfill critical physiological roles. The protein "transferrin" functions physiologically to:
(A) Bind and transport iron safely in the blood plasma
(B) Provide structural elasticity to the skin
(C) Act as an antibody in the immune response
(D) Catalyze the digestion of complex lipids

2003

273. The Protein Digestibility Corrected Amino Acid Score (PDCAAS) is calculated by multiplying the true fecal protein digestibility by the:
(A) Total nitrogen content
(B) Net protein ratio
(C) Amino acid score (ratio of the limiting amino acid to the reference pattern)
(D) Total energy density of the food

2003

274. Consider the following statements regarding the chemical structural properties of food lipids:
I. Saturated fatty acids pack closely together, resulting in higher melting points.
II. Cis-double bonds introduce a rigid "kink" into the hydrocarbon chain, lowering the melting point.
III. Trans-double bonds completely eliminate the hydrocarbon chain, making the lipid fully water-soluble.
IV. Phospholipids contain a diacylglycerol backbone covalently attached to a hydrophilic phosphate head group.
V. Triglycerides are non-polar, hydrophobic molecules.
Which of the above statement(s) is/are INCORRECT?
(A) I, II and IV
(B) Only III
(C) III and V
(D) II, III and V

2021

275. Which of the following pairs represents the parent essential fatty acids in human nutrition?
(A) Linoleic acid and Alpha-linolenic acid
(B) Stearic acid and Oleic acid
(C) Arachidonic acid and Eicosapentaenoic acid
(D) Palmitic acid and Myristic acid

2011

276. Selenium is a component of the amino acid selenocysteine, which is located in the active site of which antioxidant enzyme?
(A) Catalase
(B) Superoxide distmutase
(C) Glutathione peroxidase
(D) Polyphenol oxidase

2008

277. The intestinal absorption of magnesium occurs through which two pathways?
(A) Active transport via intrinsic factor and simple exocytosis
(B) Carrier-mediated uptake via the GLUT4

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2010

237. The processing-based detoxification of raw cassava to remove cyanogenic glycosides requires which crucial step prior to washing or fermenting?
(A) Freezing the intact root
(B) Crushing tissue to mix enzyme and substrate
(C) Coating the whole root in wax
(D) Boiling the whole root unpeeled

2024

238. Arrange the following sequence of events detailing the biochemical pathway of aflatoxin B1 toxicity in the human liver:
I. Formation of aflatoxin-N7-guanine adducts
II. Ingestion and hepatic uptake of Aflatoxin B1
III. Cytochrome P450-mediated epoxidation into Aflatoxin B1-8,9-epoxide
IV. Mutation of the p53 tumor suppressor gene
(A) II, III, I, IV
(B) II, I, III, IV
(C) III, II, IV, I
(D) I, II, III, IV

2013

239. Which of the following peanut proteins is recognized as one of the most potent major allergens associated with severe IgE-mediated type I hypersensitivity?
(A) Glycinin
(B) Phaseolin
(C) Zein
(D) Arachin (Ara h 1)

2021

240. Which of the following combinations perfectly exemplifies a synbiotic relationship?
(A) Lactobacillus acidophilus combined with highly refined wheat starch
(B) Streptococcus thermophilus combined with saturated animal fat
(C) Bifidobacterium animalis and fructooligosaccharides
(D) Escherichia coli combined with raw cellulose in the gut

2011

241. "Glucosinolates," known for their potential targeted health benefits, are predominantly sourced from which botanical family?
(A) Brassicaceae (e.g., broccoli, cabbage)
(B) Solanaceae (e.g., tomatoes, peppers)
(C) Apiaceae (e.g., carrots, celery)
(D) Rosaceae (e.g., apples, pears)

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2008

242. The synthetic food additive "Aspartame" is a dipeptide derivative composed of the methyl ester of which two amino acids?
(A) Glutamine and Lysine
(B) Arginine and Glycine
(C) Aspartic acid and Phenylalanine
(D) Methionine and Tyrosine

2003

243. The "Atwater specific factors" differ from the "Atwater general factors" because the specific factors explicitly account for:
(A) Precise variations in heat of combustion and digestibility for specific foods
(B) The specific gravity of the food matrix
(C) The individual consumer's exact basal metabolic rate
(D) The ambient temperature at the time of consumption

2007

244. The Recommended Dietary Allowance (RDA) for Vitamin C factors in its role as a cofactor for which specific physiological process?
(A) The carboxylation of glutamic acid residues in prothrombin
(B) The reduction of oxidized glutathione in erythrocytes
(C) The hydroxylation of proline and lysine during collagen synthesis
(D) The transamination of amino acids in the liver

2011

245. Which of the following conditions is an absolute requirement for starch gelatinization to proceed?
(A) Heating in the presence of adequate water
(B) The presence of a strong acid
(C) Cooling to sub-zero temperatures
(D) The complete absence of oxygen

2023

246. If a carrot has a high Glycemic Index (GI) but a very low carbohydrate density per standard serving, its resulting Glycemic Load (GL) will be:
(A) Exceptionally high
(B) Very low
(C) Mathematically incalculable
(D) Equal exactly to 71

2010

247. Which highly complex, cross-linked phenolic polymer is an insoluble fiber that provides

(B) Acting as a potent bronchodilator in severe asthma
(C) Completely preventing heavy metal absorption
(D) Promoting beneficial changes in body composition (reducing adiposity)

2023

290. Which of the following is a widely used food additive classified as an anti-caking agent?
(A) Silicon dioxide
(B) Sodium benzoate
(C) Monosodium glutamate
(D) Tartrazine

2007

291. The "Thermic Effect of Food" (TEF) accounts for approximately what percentage of total daily energy expenditure in a healthy, moderately active adult?
(A) 2%
(B) 10%
(C) 30%
(D) 50%

2015

292. If the requirement for absorbed elemental iron is 1.5 mg/day and the average dietary bioavailability is 10%, the Recommended Dietary Allowance (RDA) would be theoretically calculated as:
(A) 1.5 mg/day
(B) 5.0 mg/day
(C) 150.0 mg/day
(D) 15.0 mg/day

2007

293. The specific stereochemical difference separating D-glucose from L-glucose fundamentally resides in:
(A) All chiral centers are perfectly inverted
(B) Carbon-1 (anomeric carbon)
(C) Carbon-2
(D) Carbon-5 (the highest-numbered chiral center)

2007

294. What is the physiological advantage of consuming very low Glycemic Index (GI) foods prior to prolonged aerobic exercise?
(A) Maximize an immediate, transient spike in blood insulin
(B) Rapidly empty the stomach completely within 5 minutes
(C) Ensure sustained glucose availability over the event duration
(D) Completely inhibit the utilization of free fatty acids

2002

295. High-viscosity soluble dietary fibers lower postprandial lipemia by physically hindering the interaction of dietary triglycerides with which critical digestive enzyme?
(A) Gastric pepsin
(B) Salivary amylase
(C) Intestinal enterokinase
(D) Pancreatic lipase

2008

296. Elastin's unique elasticity is biochemically derived from cross-linking involving which unique amino acid derivative?
(A) Desmosine
(B) Hydroxyproline
(C) Cystine
(D) Selenomethionine

2002

297. The "Net Protein Ratio" (NPR) represents an improvement over the Protein Efficiency Ratio (PER) because NPR precisely accounts for:
(A) The exact number of essential amino acids present
(B) The weight loss observed in a non-protein control group
(C) The amount of protein mathematically excreted in the feces
(D) The strictly thermal destruction of lysine in the food

2012

298. Which specific structural feature within a polyunsaturated fatty acid presents the most vulnerable site for initial hydrogen abstraction during autoxidation?
(A) The terminal methyl carbon at the end of the fatty acid chain
(B) The carbonyl carbon of the ester linkage in the triglyceride
(C) The isolated saturated carbons near the carboxyl end of the chain
(D) The bis-allylic methylene carbon located between two double bonds

2002

299. The "Omega-3 Index" is a clinical biomarker representing the combined percentage of which two fatty acids integrated into red blood cell membranes?
(A) Eicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA)
(B) Alpha-linolenic acid and Oleic acid

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crops such as peanuts, maize, and tree nuts under warm and humid storage conditions. Chronic ingestion of contaminated food is a major risk factor for the development of hepatocellular carcinoma.

45. (B) The enzymatic deficiency of lactase in the small intestine
Lactose intolerance is a common metabolic condition resulting from an insufficient production of the enzyme lactase by the mucosal cells of the small intestine. Without adequate lactase, the disaccharide lactose cannot be hydrolyzed into glucose and galactose. This leads to the fermentation of undigested lactose by colonic bacteria, causing symptoms such as bloating, flatulence, and diarrhea, rather than an immune response.

46. (A) II, III, I, IV
Protein digestion begins in the stomach, where hydrochloric acid denatures the complex protein structures. This acidic environment activates pepsin, which starts the hydrolysis of peptide bonds. In the small intestine, the enzyme enteropeptidase activates trypsinogen into trypsin, which further breaks down proteins. Finally, the resulting dipeptides and free amino acids are absorbed into the enterocytes through specialized active transport systems.

47. (B) A probiotic paired with a prebiotic that selectively favors its growth
A synbiotic is a functional food product or dietary supplement that contains both a probiotic microorganism and a prebiotic substrate. The primary goal of this combination is to enhance the survival and colonization of the probiotic within the gastrointestinal tract. By providing a specific fermentable fiber that selectively favors the growth of the beneficial bacteria, synbiotics provide a synergistic health benefit.

48. (C) Cyclooxygenase-2 (COX-2) and Lipoxygenase (LOX) pathways
Curcumin is the primary bioactive polyphenolic compound found in turmeric and is widely recognized for its potent anti-inflammatory properties. It exerts these effects by modulating multiple molecular targets within inflammatory signaling pathways. Specifically, it inhibits the activity of enzymes such as cyclooxygenase-two and lipoxygenase, which are responsible for the synthesis of pro-inflammatory mediators like prostaglandins and leukotrienes in the body.

49. (A) Generally Recognized As Safe
In the United States food safety regulations, the acronym GRAS stands for Generally Recognized As Safe. This designation is applied to food additives or substances that are considered safe by qualified experts under the conditions of their intended use. For a substance to achieve this status, there must be a consensus of scientific evidence demonstrating its safety for human consumption.

50. (D) Proteins
The specific dynamic action, also known as the thermic effect of food, refers to the increase in metabolic rate following the ingestion of nutrients. Among the three macronutrients, proteins exhibit the highest metabolic cost because the processes of deamination, urea synthesis, and protein turnover are energy-intensive. Approximately twenty to thirty percent of the energy content of protein is used during processing.

51. (B) Basal metabolic rate
For most sedentary adults, the basal metabolic rate constitutes the largest component of total daily energy expenditure, typically accounting for sixty to seventy-five percent of the total calories burned. This energy is used to maintain essential life-sustaining functions such as respiration, circulation, and cellular maintenance while the body is at rest. Other components, such as physical activity and thermogenesis, contribute less.

52. (C) Retrogradation
Retrogradation is a physical process that occurs when gelatinized starch is cooled after cooking. During this time, the amylose and amylopectin chains realign and crystallize into a more ordered and rigid structure. This transformation leads to the formation of resistant starch, which is highly resistant to enzymatic hydrolysis in the small intestine, thereby providing benefits similar to those of dietary fiber.

53. (B) 12
The glycemic load is determined by multiplying the glycemic index of a food by the amount of available carbohydrates per serving and then dividing the total by one hundred. In this specific case, multiplying the glycemic index of

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ANSWERS

1. (A) The surplus heat produced by the body during the digestion, absorption, and metabolism of nutrients
The specific dynamic action represents the internal energy expenditure associated with processing dietary nutrients. This metabolic cost involves the energy required for the ingestion, digestion, absorption, transport, and eventual storage of macronutrients. Consequently, the body generates surplus heat as a byproduct of these biochemical reactions, increasing the overall metabolic rate above the resting baseline levels.

2. (C) 97.5 percent
The recommended dietary allowance is designed to cover the nutritional needs of nearly all healthy individuals within a specific life stage and gender group. It is calculated by adding two standard deviations to the estimated average requirement. This statistical approach ensures that the intake level is sufficient to meet the physiological requirements of ninety-seven point five percent of the population.

3. (A) Inulin
Inulin serves as a storage carbohydrate in various plants and is classified as a fructan. It consists of a linear chain of fructose molecules joined by specific glycosidic linkages. Because it is not hydrolyzed by human digestive enzymes in the small intestine, it reaches the colon intact, where it undergoes fermentation by beneficial gut bacteria, acting as a prebiotic.

4. (D) The rate at which the food is digested and its carbohydrate content is absorbed as glucose
The glycemic index serves as a relative ranking system for carbohydrates based on how quickly they affect blood sugar levels. This measurement is primarily determined by the digestive efficiency and the speed of intestinal absorption of glucose into the bloodstream. Factors such as food structure, fiber content, and processing methods significantly influence the rate at which these biochemical processes occur.

5. (B) They delay gastric emptying and attenuate postprandial blood glucose absorption
High-viscosity soluble fibers interact with water in the gastrointestinal tract to form a thick, gel-like matrix. This physiological change increases the viscosity of chyme, which physically slows down the movement of food from the stomach into the duodenum. Consequently, the rate of carbohydrate hydrolysis and subsequent glucose absorption is significantly reduced, leading to flattened postprandial blood sugar responses.

6. (C) Derived proteins are naturally occurring complex proteins found intact in raw foods.
Derived proteins are substances produced through the chemical or physical modification of naturally occurring simple or conjugated proteins. This group includes products of denaturation or partial hydrolysis, such as proteoses, peptones, and peptides. Unlike primary proteins, these are not found in their native state within raw food sources but emerge during food processing, cooking, or the early stages of digestion.

7. (D) The terminal ileum
The digestible indispensable amino acid score provides a refined measure of protein quality by analyzing amino acid absorption at the end of the small intestine. By sampling content from the terminal ileum, this method avoids the confounding effects of microbial protein synthesis occurring in the large intestine. This approach allows for a more accurate assessment of the true nutritional value.

8. (A) The abstraction of a hydrogen atom from a methylene carbon
The initiation phase of lipid autoxidation is triggered by the removal of a hydrogen atom from a fatty acid chain, typically at a methylene group. This biochemical event creates a highly reactive carbon-centered lipid radical. Factors such as heat, ultraviolet light, or transition metal catalysts facilitate this initial step, which eventually leads to the formation of peroxyl radicals and hydroperoxides.

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9. (B) Linoleic acid
Linoleic acid is an essential omega-six fatty acid that cannot be synthesized by the human body and must be obtained through the diet. Within the liver, it undergoes a series of enzymatic desaturation and elongation reactions. Specifically, it is converted into gamma-linolenic acid and eventually into arachidonic acid, which serves as a critical precursor for the synthesis of pro-inflammatory eicosanoids.

10. (B) P-3, Q-1, R-2, S-4
Trace elements serve as vital components of various metalloenzymes that regulate essential metabolic processes. Zinc is a cofactor for carbonic anhydrase, while selenium is required for glutathione peroxidase activity. Copper is essential for the function of cytochrome c oxidase in the electron transport chain. Molybdenum acts as a critical component for xanthine oxidase, which is involved in the catabolism of purines.

11. (A) High levels of circulating hepcidin
Hepcidin is a regulatory hormone produced by the liver that serves as the master controller of systemic iron homeostasis. It functions by binding to ferroportin, the only known cellular iron exporter found on the surface of enterocytes. This binding triggers the degradation of ferroportin, thereby preventing the release of absorbed dietary iron into the bloodstream and effectively reducing its overall bioavailability.

12. (C) Lysine
Most cereal grains, including wheat, rice, and maize, are considered incomplete protein sources because they do not contain sufficient amounts of all essential amino acids. In these commodities, lysine is typically the first limiting amino acid, meaning its concentration is the lowest relative to human requirements. Consequently, the nutritional quality of cereal-based diets is often improved by combining them with lysine-rich legumes.

13. (D) Globulins
Based on the Osborne classification system, globulins are proteins that remain insoluble in pure water but dissolve readily in dilute salt solutions. These proteins constitute the major storage fraction in legume seeds, such as beans and peas. They provide a concentrated source of nitrogen and amino acids required by the developing plant embryo during germination and are characterized by their high molecular weight.

14. (C) Lycopene
Lycopene is a vibrant red carotenoid pigment and a powerful antioxidant found in high concentrations in tomatoes and watermelons. Unlike many other carotenoids, it does not possess provitamin A activity because it lacks a beta-ionone ring. Its structural configuration allows it to effectively quench singlet oxygen and protect cellular membranes from oxidative damage caused by free radicals in the body.

15. (B) Methionine
The biosynthesis of the gaseous plant hormone ethylene is a critical process for the ripening of climacteric fruits. This metabolic pathway begins with the essential amino acid methionine, which is converted into S-adenosylmethionine. Subsequently, this intermediate is transformed into one-aminocyclopropane-one-carboxylic acid, which serves as the immediate precursor that is oxidized by specific enzymes to release the ethylene gas.

16. (D) Accumulation of reducing sugars caused by cold-induced sweetening
When potatoes are stored at temperatures below four degrees Celsius, they undergo a biochemical phenomenon known as cold-induced sweetening. This process involves the enzymatic breakdown of starch into reducing sugars, primarily glucose and fructose. The accumulation of these sugars is problematic for food processing because they react with amino acids during high-temperature cooking to produce undesirable dark colors and acrylamide.

17. (A) Provitamin A (β-carotene)
Golden Rice is a genetically modified variety developed to address vitamin A deficiency in populations dependent on rice as a staple food. Scientists engineered the rice endosperm to produce beta-carotene, a provitamin A precursor, by inserting genes from maize and soil bacteria. This biosynthetic modification gives the rice grains their characteristic yellow-orange color and provides a bioavailable source of essential nutrients.

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18. (C) The hydroxyl groups that can donate hydrogen to free radicals
Plant polyphenols exhibit potent antioxidant properties due to their unique molecular structure, which contains multiple aromatic rings with attached hydroxyl groups. These hydroxyl groups are capable of donating hydrogen atoms or electrons to neutralize highly reactive free radicals and reactive oxygen species. This chemical stabilization prevents oxidative damage to vital cellular components such as lipids, proteins, and deoxyribonucleic acid in organisms.

19. (A) Chelating divalent cations to reduce their intestinal bioavailability
Phytic acid is a naturally occurring compound found in seeds and grains that acts as the primary storage form of phosphorus. Its highly negatively charged structure allows it to function as a potent chelating agent. It binds strongly to divalent cations such as calcium, iron, and zinc in the gastrointestinal tract, forming insoluble complexes that the human body cannot absorb.

20. (D) Solanine
Solanine is a toxic glycoalkaloid naturally produced by plants in the Solanaceae family, particularly in sprouting or green potatoes. It serves as a natural defense mechanism against pests and pathogens. In humans, it acts as a potent inhibitor of the enzyme acetylcholinesterase, leading to neurological symptoms. Additionally, it can disrupt cellular membranes, causing significant gastrointestinal distress and other serious toxic effects.

21. (B) Gliadins and glutenins
Celiac disease is a chronic autoimmune disorder triggered by the ingestion of gluten, a protein complex found in wheat, barley, and it also exists in rye. Specifically, the alcohol-soluble prolamin fractions, known as gliadins in wheat, contain peptide sequences that are resistant to digestive enzymes. In genetically susceptible individuals, these peptides trigger an inflammatory immune response that damages the lining of the small intestine.

22. (A) Both A and R are true and R is the correct explanation of A.
Probiotic bacteria, such as specific strains of Lactobacillus and Bifidobacterium, play a significant role in improving lactose digestion. These microorganisms produce the enzyme beta-galactosidase, which remains active within the intestinal lumen. When lactose is consumed, this bacterial enzyme helps hydrolyze the disaccharide into its constituent monosaccharides, glucose and galactose, thereby reducing the symptoms of intolerance in individuals with low endogenous lactase.

23. (D) Hypercholesterolemia
Phytosterols are plant-derived compounds that possess a chemical structure very similar to cholesterol. When consumed, they compete with dietary and biliary cholesterol for incorporation into mixed micelles within the small intestine. This competition effectively inhibits the intestinal absorption of cholesterol, leading to a reduction in total and low-density lipoprotein cholesterol levels in the blood, which helps manage hypercholesterolemia and heart disease risk.

24. (A) Aspartame
Aspartame is a high-intensity artificial sweetener composed of the amino acids aspartic acid and phenylalanine. During metabolism, it releases phenylalanine, which can be harmful to individuals with the genetic disorder phenylketonuria who lack the enzyme to process this amino acid. Consequently, all products containing this sweetener must carry a clear warning label to prevent adverse health consequences for these specific individuals.

25. (B) High lean body mass (fat-free mass)
Basal metabolic rate represents the minimum amount of energy required to maintain vital physiological functions while the body is at complete rest. The most significant determinant of this rate is the amount of lean body mass, which includes muscle, bones, and organs. Lean tissue is much more metabolically active than adipose tissue, meaning individuals with higher muscle mass expend more energy.

26. (B) The individual's personal dietary preferences
The recommended dietary allowance is a scientific estimate designed to meet the nutritional requirements of a specific population group. It is established based on the estimated average requirement and accounts for individual variability and the bioavailability of nutrients from various food sources. However, personal dietary preferences and cultural habits are

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(C) Linoleic acid and Arachidonic acid
(D) Palmitic acid and Stearic acid

2025

300. Zinc deficiency severely impairs the functional capability of which vital enzyme involved in regulating blood pH?
(A) Cytochrome c oxidase
(B) Carbonic anhydrase
(C) Xanthine oxidase
(D) Superoxide dismutase

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calcium is available for bone mineralization and other vital physiological processes such as muscle contraction.

36. (D) Methionine
Pulse crops, such as lentils, chickpeas, and beans, are excellent sources of plant-based protein but are typically deficient in sulfur-containing amino acids. Specifically, methionine is the limiting amino acid in these legumes, which reduces their overall biological value. To achieve a complete amino acid profile, pulses are traditionally consumed alongside cereal grains, which are relatively rich in methionine but lack sufficient lysine.

37. (B) Glutamine and Proline
The alcohol-soluble storage proteins in wheat, known as gliadins, possess a unique amino acid composition that influences the functional properties of dough. They are exceptionally rich in glutamine and proline, which together account for a large percentage of the total amino acid content. Proline residues prevent the formation of regular alpha-helices, leading to the characteristic extensibility and viscosity of wheat-based doughs.

38. (C) Allicin
The characteristic pungency and aroma of garlic are generated only when the plant tissues are physically damaged, such as by crushing or chopping. This action brings the enzyme alliinase into contact with its substrate, alliin. The resulting enzymatic reaction rapidly produces allicin, a volatile organosulfur compound. Allicin is responsible for the distinct flavor and also possesses various antimicrobial and health-promoting properties.

39. (D) Ethylene
Climacteric fruits are characterized by a sudden and dramatic increase in the rate of cellular respiration and oxygen consumption during the ripening process. This physiological event is tightly regulated by a corresponding sharp rise in the biosynthesis of ethylene, a gaseous plant hormone. Ethylene acts as a master switch that coordinates the various biochemical changes associated with ripening, such as softening and color.

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40. (A) Depolymerization of cell wall pectin by polygalacturonase
The softening of fruit tissues during ripening is primarily the result of the enzymatic degradation of the primary cell wall and the middle lamella. The enzyme polygalacturonase plays a critical role in this process by catalyzing the depolymerization of pectin chains. As these structural polysaccharides are broken down into smaller, more soluble fragments, the rigid architecture of the fruit weakens significantly.

41. (B) Phytic acid
Biofortification aims to increase the concentration of essential minerals like iron and zinc in staple crops through breeding or genetic engineering. However, the presence of phytic acid in these plants often limits the nutritional benefit. Phytic acid acts as a potent anti-nutrient by binding to these minerals in the digestive tract, forming insoluble complexes that drastically reduce their absorption and bioavailability.

42. (B) A 15-carbon skeleton arranged in a (C6-C3-C6) phenyl ring configuration
Flavonoids are a diverse group of plant secondary metabolites characterized by a specific fifteen-carbon backbone. This core structure consists of two phenyl rings, designated as rings A and B, connected by a three-carbon heterocyclic ring, designated as ring C. This C6-C3-C6 configuration allows for various substitutions, leading to the wide range of colors and antioxidant properties observed in different plant species.

43. (D) Thermal processing (e.g., boiling or autoclaving)
Raw soybeans contain Bowman-Birk protease inhibitors, which are small proteins that interfere with the activity of digestive enzymes like trypsin and chymotrypsin. These inhibitors are heat-labile, meaning they can be effectively inactivated through thermal processing. Methods such as boiling, steaming, or autoclaving are essential to destroy these anti-nutritional factors, thereby improving the protein digestibility and the overall safety of soy.

44. (C) Aspergillus
Aflatoxin B1 is a highly toxic and carcinogenic secondary metabolite produced primarily by certain species of the fungal genus Aspergillus, specifically Aspergillus flavus and Aspergillus parasiticus. These molds commonly contaminate

63. (D) Glucosinolates
The pungent and characteristic flavors of Brassica vegetables, such as mustard and cabbage, are derived from the enzymatic breakdown of glucosinolates. These sulfur-containing secondary metabolites are stored separately from the enzyme myrosinase within the plant cells. When the tissue is physically damaged by cutting or chewing, the enzyme and substrate mix, releasing volatile compounds such as isothiocyanates, nitriles, and thiocyanates.

64. (C) Conversion of chloroplasts into chromoplasts
During the ripening process of many fruits, a significant visual change occurs as the green color fades and vibrant hues of red, yellow, or orange appear. This transformation is biochemically driven by the conversion of chloroplasts into chromoplasts. This process involves the degradation of chlorophyll molecules and the simultaneous synthesis and accumulation of various carotenoid pigments within the specialized plastids.

65. (B) Solidification of membrane lipids leading to loss of membrane semi-permeability
Chilling injury is a physiological disorder that affects sensitive tropical and subtropical produce when stored at low temperatures above freezing. The primary biochemical cause is the physical transition of the cellular membrane lipids from a fluid, liquid-crystalline state to a rigid, solid-gel state. This phase change leads to a loss of membrane semi-permeability, resulting in cellular leakage, metabolic imbalances, and tissue damage.

66. (D) Application of micronutrient-rich fertilizers to the soil or foliage
Agronomic biofortification is a strategy used to improve the nutritional quality of food crops by increasing the concentration of essential micronutrients through soil management practices. This approach involves the application of mineral fertilizers to the soil or directly to the plant foliage. By enhancing the nutrient availability in the environment, the crops absorb and accumulate higher levels of minerals like zinc.

67. (A) Tannins
Tannins are a class of polyphenolic compounds widely distributed in the plant kingdom, known for their ability to bind and precipitate proteins. This property is responsible for the characteristic astringent or dry sensation experienced when consuming unripe fruits or green tea. Tannins react with the proteins in human saliva, causing them to aggregate and reducing their lubricating properties in the mouth.

68. (C) Calcium
Dietary oxalates are potent anti-nutritional factors found in various vegetables and grains. Their negative impact on nutrition is primarily due to their high affinity for divalent metal ions, especially calcium. Oxalates react with calcium in the digestive tract to form calcium oxalate, a highly insoluble salt that cannot be absorbed into the bloodstream, thereby significantly lowering the dietary calcium bioavailability.

69. (A) Mycotoxins produced by Claviceps purpurea
Ergotism is a serious toxic condition resulting from the consumption of cereal grains, particularly rye, contaminated with the fungus Claviceps purpurea. This mold produces a variety of ergot alkaloids, which are potent mycotoxins. These toxins exert powerful effects on the nervous and vascular systems, leading to symptoms such as hallucinations, severe vasoconstriction, gangrene of the extremities, and other life-threatening effects.

70. (A) Both A and R are true and R is the correct explanation of A.
Peanut allergy is a severe type one hypersensitivity reaction mediated by the immune system. When a sensitized individual ingests peanut proteins, the allergens cross-link immunoglobulin E antibodies on the surface of mast cells. This triggers the massive release of histamine and other mediators, which can cause anaphylaxis, a rapid and potentially fatal systemic reaction characterized by respiratory distress and hypotension.

71. (A) Bifidobacterium and Lactobacillus
Prebiotics are non-digestible dietary components, such as certain oligosaccharides, that provide a selective substrate for beneficial bacteria in the large intestine. By bypassing digestion in the upper gastrointestinal tract, they reach the colon where they are fermented. This process primarily stimulates the growth and metabolic activity of health-promoting bacterial genera, most notably Bifidobacterium and Lactobacillus, which improve gut health.

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eighty by fifteen grams of carbohydrate results in twelve hundred. Dividing twelve hundred by one hundred yields a final glycemic load value of twelve.

54. (D) Increased transit time of chyme through the gastrointestinal tract
Insoluble dietary fibers, such as cellulose and hemicellulose, play a crucial role in maintaining digestive health by adding bulk to the stool. These fibers do not dissolve in water and pass through the gastrointestinal tract largely intact. A diet lacking in these fibers often leads to an increased transit time of chyme, which can contribute to chronic constipation and other digestive issues.

55. (B) Conjugated metalloprotein
Hemoglobin is a complex protein found in red blood cells that is classified as a conjugated metalloprotein. It consists of a protein component called globin and a non-protein prosthetic group known as heme, which contains a central iron ion. This iron-containing group is essential for the reversible binding and transport of oxygen from the lungs to the various tissues throughout the body.

56. (C) The true digestibility of the protein
Net protein utilization is a comprehensive metric used to evaluate protein quality by measuring the percentage of dietary nitrogen that is actually retained by the body. Unlike biological value, which only considers the nitrogen that has been absorbed, net protein utilization explicitly accounts for the digestibility of the protein. It is mathematically equivalent to the biological value multiplied by the digestibility.

57. (D) Lipases
Hydrolytic rancidity in food lipids is a degradation process characterized by the release of free fatty acids from triacylglycerols. This reaction is primarily mediated by a class of enzymes called lipases, which catalyze the hydrolysis of the ester bonds between the glycerol backbone and the fatty acid chains. This process can produce off-flavors and odors, especially in dairy products and fats.

58. (C) I, III and IV
Saturated fatty acids lack double bonds and are generally more stable than unsaturated fatty acids, which contain one or more double bonds and are highly susceptible to oxidative rancidity. Stearic acid is a common eighteen-carbon saturated fatty acid found in animal fats. In contrast, trans-unsaturated fatty acids typically have higher melting points and more linear structures than their corresponding cis-isomers.

59. (B) Cobalt
Cobalt is an essential trace element whose primary biological role in humans is serving as the central metal ion in the structure of vitamin B12, also known as cyanocobalamin. This vitamin is critical for DNA synthesis, red blood cell formation, and the maintenance of a healthy nervous system. Without cobalt, the vitamin cannot be formed, leading to severe hematological and neurological problems.

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60. (B) Oxalic acid
Oxalic acid is a naturally occurring organic acid found in various plant foods, such as spinach and rhubarb. It acts as a potent anti-nutrient by binding strongly to dietary calcium in the gastrointestinal tract, forming insoluble calcium oxalate crystals. These crystals cannot be absorbed by the body, which significantly reduces the overall bioavailability of calcium and may contribute to kidney stones.

61. (A) Linoleic acid and vitamin E
Oilseeds like sunflower and safflower are highly valued in human nutrition primarily for their abundant content of linoleic acid, an essential omega-six polyunsaturated fatty acid. Additionally, these seeds are excellent sources of vitamin E, which acts as a powerful fat-soluble antioxidant. Vitamin E protects the polyunsaturated fats within the seeds and the human body from oxidative damage caused by free radicals.

62. (C) Prolamins
Prolamins are a major group of storage proteins found in cereal grains, characterized by their unique solubility properties. They are insoluble in water and absolute ethanol but dissolve readily in seventy to eighty percent aqueous ethanol. Zein is the specific prolamin found in maize and is notably rich in the amino acids proline and glutamine, while being deficient in lysine and tryptophan.

not used as mathematical parameters in the statistical calculation of these values.

27. (A) Amylose forms helical structures that bind iodine for a blue color
Amylose is a linear polymer of glucose units linked by alpha-one-four glycosidic bonds that typically forms a helical structure. This configuration allows it to trap iodine molecules within the helix, resulting in the characteristic deep blue color used in starch testing. In contrast, amylopectin is highly branched and produces a reddish-purple color when reacting with iodine due to its different structural arrangement.

28. (C) The GI times the grams of carbohydrate in a portion, divided by 100
Glycemic load is a nutritional measurement that accounts for both the quality and the quantity of carbohydrates in a specific food serving. It is calculated by multiplying the glycemic index of the food by the total grams of available carbohydrate in the portion and then dividing the result by one hundred. This provides a more comprehensive estimate of the actual impact on blood sugar.

29. (D) Fermentation by colonic microbiota to produce short-chain fatty acids
Soluble dietary fibers like pectin are not digested by human enzymes in the small intestine but are readily fermented by beneficial bacteria in the colon. This biochemical process produces short-chain fatty acids, such as acetate, propionate, and butyrate. These metabolites provide energy for colonocytes, lower the luminal pH, and exert various systemic health benefits, including improved lipid metabolism and enhanced immune function.

30. (C) An incomplete protein is deficient in one or more essential amino acids.
An incomplete dietary protein is characterized by its failure to provide adequate amounts of one or more of the nine essential amino acids required by the human body. These missing or deficient amino acids are referred to as limiting amino acids. While most animal-based proteins are complete, many plant proteins lack specific essential amino acids, necessitating the consumption of complementary protein sources.

31. (B) The weight gain of a test animal divided by the protein intake
The protein efficiency ratio is a biological method used to assess the nutritional quality of a protein source, typically using young, growing rats as a test model. It is calculated by measuring the total weight gain of the animal over a specific period and dividing it by the total weight of the protein consumed during that same duration. This ratio indicates efficiency.

32. (D) The degree of unsaturation of the fatty acids
The iodine value is a chemical parameter used to quantify the total number of carbon-carbon double bonds present in a fat or oil sample. It measures the amount of iodine, in grams, that is absorbed by one hundred grams of the lipid. A higher iodine value indicates a greater degree of unsaturation, which correlates with higher fluidity and increased susceptibility to oxidation.

33. (A) Retinal photoreceptors and neuronal membranes
Docosahexaenoic acid is a long-chain omega-three polyunsaturated fatty acid that is essential for the proper development and function of the central nervous system. It is found in extremely high concentrations in the phospholipid bilayers of retinal photoreceptor cells and neuronal membranes. Maintaining adequate levels of this fatty acid is critical for optimal visual acuity and the efficient transmission of neural signals.

34. (D) Only IV
Macro-minerals are required by the body in relatively large quantities, typically exceeding one hundred milligrams per day, while trace elements are needed in much smaller amounts. Calcium, magnesium, and phosphorus are classic macro-minerals with structural and regulatory roles. Iron, however, is classified as a trace element because its daily requirement is low, and its primary function is oxygen transport via hemoglobin.

35. (A) Vitamin D (1,25-dihydroxycholecalciferol)
The active form of vitamin D, known as one-twenty-five-dihydroxycholecalciferol, is the primary hormonal regulator of calcium homeostasis. It enhances the intestinal absorption of dietary calcium by stimulating the expression of specific transport proteins, such as calbindin, in the enterocytes of the small intestine. This mechanism ensures that sufficient

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72. (C) Stilbenes
Resveratrol is a well-known bioactive polyphenolic compound found in various plants, particularly in the skins of red grapes and in peanuts. It belongs to the structural class of stilbenes, which are characterized by a 1,2-diphenylethylene core. Resveratrol has gained significant attention as a nutraceutical due to its potent antioxidant, anti-inflammatory, and potential cardiovascular protective effects in human health.

73. (D) Antioxidant to prevent lipid rancidity
Butylated hydroxytoluene is a widely used synthetic food additive that functions as a powerful antioxidant. Its primary role in food processing is to prevent or delay the oxidative rancidity of fats and oils by neutralizing free radicals. By stabilizing the lipid components, BHT helps to preserve the flavor, color, and nutritional quality of various processed foods, extending their overall shelf life.

74. (C) Metabolizable energy subtracts energy lost in digestion, feces, and urine
The gross energy of a food represents the total amount of heat released when it is completely combusted in a bomb calorimeter. However, not all of this energy is available for human metabolism. Metabolizable energy is a more accurate measure of the energy that can be utilized by the body, as it subtracts the energy lost in feces and urine.

75. (B) The mean weight of healthy adults in the specific age and gender group
The reference body weight is a critical parameter used by nutritional experts to establish the recommended dietary allowances for a given population. This value is based on the average weight of healthy, well-nourished adults of a specific age and gender who have a body mass index within the normal range. It serves as the baseline for calculating nutrient requirements for individuals.

76. (D) D-glucose and D-galactose
Epimers are a specific type of stereoisomer where two sugars differ in their configuration around only one chiral carbon atom. Glucose and galactose are classic examples of C-4 epimers because they have identical structures except for the spatial arrangement of the hydroxyl group and hydrogen atom at the fourth carbon. In contrast, glucose and mannose are considered C-2 epimers.

77. (A) Slower intestinal hydrolysis and steady glucose absorption
Low glycemic index foods are characterized by carbohydrates that are digested and absorbed at a slower and more sustained rate compared to high GI alternatives. This steady release of glucose into the portal circulation prevents the rapid and excessive spikes in blood sugar that typically follow the ingestion of refined sugars. Consequently, there is a more controlled and moderate insulin response.

78. (C) Increasing fecal bulk and promoting laxation
Insoluble dietary fibers, such as cellulose and lignin, do not dissolve in water and are resistant to fermentation by colonic bacteria. Their primary physiological function is to add physical bulk to the stool and stimulate intestinal peristalsis. By mechanically promoting the movement of waste through the digestive tract, these fibers effectively improve laxation and help prevent the development of chronic constipation.

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79. (A) Assisting in the correct folding of newly synthesized polypeptide chains
Chaperone proteins are specialized molecules found in all living organisms that play a fundamental role in protein biochemistry. Their primary function is to assist in the correct folding of newly synthesized polypeptide chains into their functional three-dimensional shapes. By preventing inappropriate aggregations and refolding damaged proteins, chaperones ensure that cellular proteins remain stable and biologically active under various physiological conditions.

80. (D) The amino acid pattern of an infant as defined by FAO/WHO
The amino acid score is a method used to evaluate the nutritional quality of a food protein by comparing its essential amino acid content to a standard reference pattern. The Food and Agriculture Organization and World Health Organization have defined this reference based on the amino acid requirements of a healthy infant. This comparison identifies the limiting amino acid in the protein.

81. (B) Carbon-carbon double bonds in unsaturated fatty acids
Oxidative rancidity is a complex biochemical process that involves the degradation of unsaturated fatty acids within food lipids. This reaction is initiated by the interaction of oxygen with the carbon-carbon double bonds in the fatty acid chains, leading to the formation of hydroperoxides. These unstable intermediates eventually break down into volatile compounds like aldehydes and ketones, which produce undesirable off-flavors and odors.

82. (A) P-4, Q-3, R-1, S-2
Essential fatty acids and their derivatives are classified based on the position of the first double bond from the methyl end. Linoleic and alpha-linolenic acids are the primary omega-six and omega-three precursors, respectively. Through enzymatic pathways, linoleic acid is converted into long-chain derivatives like arachidonic acid, while alpha-linolenic acid is transformed into longer omega-three chains such as eicosapentaenoic acid and docosahexaenoic acid.

83. (D) Goiter
Iodine is an essential trace element required for the synthesis of thyroid hormones, which regulate metabolism and growth. A chronic deficiency of dietary iodine leads to the overstimulation of the thyroid gland by thyroid-stimulating hormone, causing the gland to enlarge significantly. This clinical condition is known as a goiter and is a common manifestation of iodine deficiency in adult populations.

84. (C) Concomitant intake of ascorbic acid (Vitamin C)
The intestinal absorption of non-heme iron, which is found in plant-based foods, is significantly influenced by other dietary components. Ascorbic acid, or vitamin C, is the most effective enhancer of non-heme iron absorption. It functions by reducing ferric iron to the more soluble ferrous form and creating stable chelates that prevent the iron from precipitating in the alkaline environment.

85. (A) 40% protein and 20% oil
Soybeans are unique among legumes because they possess an exceptionally high protein content and a significant amount of lipid. On a dry weight basis, soybeans typically contain approximately forty percent protein and twenty percent oil. This balanced macronutrient profile makes them a highly versatile and valuable crop for both human nutrition and various industrial applications, including the production of vegetable oil.

86. (D) Polymeric networks cross-linked by disulfide bonds
Glutelins represent a major fraction of cereal storage proteins, with wheat glutenin being a well-known example. These proteins are characterized by their extreme insolubility in water and neutral salts, typically requiring dilute acids or alkalis for extraction. Structurally, glutelins form large polymeric networks held together by interchain disulfide bonds, which contribute to the elasticity and strength of bread dough.

87. (C) The cleavage of the phytol tail by the enzyme chlorophyllase
The loss of the green color during fruit ripening is an enzymatic process that signals the degradation of chlorophyll molecules. This biochemical pathway is initiated by the enzyme chlorophyllase, which catalyzes the removal of the hydrophobic phytol tail from the chlorophyll structure. This conversion transforms the pigment into more water-soluble chlorophyllide, which is then further broken down into colorless metabolites.

88. (B) Citrus (e.g., Orange)
Non-climacteric fruits, such as citrus, grapes, and strawberries, differ from climacteric fruits because they do not exhibit a sudden spike in respiration or ethylene production as they ripen. These fruits must generally reach full maturity on the plant before harvest, as they do not significantly improve in quality after being picked. Citrus fruits like oranges are classic examples of this.

89. (A) Decreased O_2 and increased CO_2
Controlled atmosphere storage is a post-harvest technique used to extend the shelf life of fresh produce by precisely adjusting the composition of the air in the storage facility. This typically involves reducing the concentration of oxygen to slow down cellular respiration and increasing the level of carbon dioxide to inhibit the ripening and growth of various decay-causing microorganisms.

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90. (D) The shikimate and pteridine pathways
Folates, or vitamin B9, are essential micronutrients that are synthesized in plants through the convergence of two distinct metabolic pathways. The pteridine pathway provides the pterin moiety, while the shikimate pathway generates the para-aminobenzoic acid component. Metabolic engineering strategies for biofortifying crops with folates target the upregulation of key enzymes within these pathways to increase the overall synthesis.

91. (A) Highly acidic (pH < 3)
Anthocyanins are water-soluble plant pigments whose color and chemical stability are highly dependent on the environmental pH. In highly acidic conditions, specifically at a pH below three, anthocyanins exist predominantly as the flavylium cation, which exhibits a vibrant and characteristic red color. As the pH increases towards neutrality, the structure undergoes various transformations, leading to a shift toward purple.

92. (C) Hydrogen cyanide
Cyanogenic glycosides are natural plant toxins found in several food crops, such as cassava and sorghum. These compounds are non-toxic in their intact state, but they become hazardous when the plant tissue is damaged. This damage allows endogenous enzymes to hydrolyze the glycosides, resulting in the release of hydrogen cyanide gas. Ingesting this gas is lethal as it inhibits mitochondrial respiration.

93. (D) Blocking voltage-gated sodium channels in nerve membranes
Tetrodotoxin is a potent neurotoxin found in pufferfish and certain marine organisms. It acts with high specificity by binding to and blocking voltage-gated sodium channels on the surface of nerve and muscle cell membranes. This inhibition prevents the influx of sodium ions required for the initiation and conduction of action potentials, leading to progressive paralysis and potential death from respiratory failure.

94. (A) I, III and IV
Food allergies are immune-mediated reactions, often involving immunoglobulin E, whereas food intolerances are non-immunological and often depend on the amount of food consumed. Celiac disease is a unique autoimmune condition triggered by gluten. Unlike allergies, metabolic intolerances like lactose deficiency do not cause anaphylaxis. Understanding these distinctions is critical for the proper clinical diagnosis and management of adverse food reactions.

95. (B) Pathogen exclusion and modulation of intestinal immunity
The primary mechanism by which probiotic bacteria confer health benefits involves the modulation of the host's intestinal environment and immune system. Probiotics compete with harmful enteric pathogens for nutrients and adhesion sites on the intestinal mucosa, effectively preventing colonization. Furthermore, they strengthen the gut barrier function and interact with lymphoid tissues to enhance the overall mucosal and systemic immune responses.

96. (D) Prostate cancer
Lycopene is a potent antioxidant carotenoid that has been extensively studied for its protective role against various chronic diseases. Scientific research has consistently demonstrated a strong inverse correlation between the consumption of lycopene-rich foods and the risk of developing prostate cancer. Its ability to neutralize free radicals and modulate cellular signaling pathways is thought to be the primary biochemical mechanism.

97. (A) Sodium alginate
Sodium alginate is a natural hydrocolloid extracted from the cell walls of brown seaweeds. It is widely used in the food industry as a thickening, stabilizing, and gelling agent. A unique property of alginate is its ability to form a heat-stable gel through the cross-linking of its polymer chains in the presence of divalent cations, particularly calcium ions.

98. (C) Harris-Benedict equation
The Harris-Benedict equation is a widely used clinical tool for estimating an individual's basal metabolic rate. It calculates energy expenditure based on physiological parameters including gender, body weight, height, and age. This mathematical formula provides a reliable baseline for determining total daily energy requirements, which helps in designing personalized nutritional plans for weight management and overall health maintenance in adults.

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99. (C) 65 kg
In the updated nutritional guidelines published by the Indian Council of Medical Research and the National Institute of Nutrition in 2020, the parameters for the Indian reference man were revised. The reference man is now defined as a healthy adult between the ages of nineteen and thirty-nine with a body weight of sixty-five kilograms and a normal body mass index.

100. (D) The specific configuration of $\beta(1\rightarrow4)$ linkages
Cellulose is a complex polysaccharide that serves as a primary structural component of plant cell walls. It consists of a linear chain of thousands of glucose units joined by beta-one-four glycosidic linkages. Human digestive enzymes, such as salivary and pancreatic amylase, are structurally designed to only hydrolyze alpha-glycosidic bonds. Consequently, cellulose remains indigestible and functions as a significant component of fiber.

101. (B) Plain boiled white rice
Plain boiled white rice is classified as a high glycemic index food because its starch is rapidly digested and absorbed into the bloodstream. This leads to a quick and significant spike in postprandial blood glucose levels. In contrast, foods like lentils, whole milk, and raw carrots have lower GI values due to their higher fiber, protein, or complex carbohydrate structure.

102. (C) Pectin
Pectin is a type of soluble dietary fiber found abundantly in the cell walls of fruits and vegetables. It possesses a high water-holding capacity, allowing it to form a viscous, gel-like matrix within the stomach and small intestine. This physical property significantly increases the viscosity of the chyme, which delays gastric emptying and slows the overall rate of nutrient absorption.

103. (D) Conjugated phosphoprotein
Casein is the predominant protein fraction found in mammalian milk, accounting for approximately eighty percent of the total protein. It is classified as a conjugated phosphoprotein because it contains multiple phosphate groups covalently attached to specific serine and threonine amino acid residues. These phosphate groups are essential for binding calcium and maintaining the stability of the large casein micelle structures.

104. (C) 1.00
The protein digestibility corrected amino acid score is a standard method used to evaluate the nutritional quality of proteins. To ensure consistency and prevent the overestimation of the protein's contribution to a balanced diet, the maximum score is truncated at one point zero zero. Any protein that meets or exceeds the human requirement for all essential amino acids receives this score.

105. (A) The combination of two free radicals to form a stable, non-radical molecule
Termination is the final stage of the lipid autoxidation chain reaction. During this phase, the concentration of free radicals decreases as they react with one another to form stable, non-radical end products. For example, two lipid radicals or two peroxyl radicals may combine, effectively stopping the self-propagating cycle. This process prevents the further oxidative degradation of the unsaturated fatty acids.

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106. (A) III, I, IV, II
Lipid autoxidation is a self-sustaining free radical chain reaction that occurs in several distinct biochemical phases. The process begins with initiation, where a radical is first formed. This is followed by propagation, during which the reaction spreads through the fatty acid chains. Next, hydroperoxides decompose into volatile compounds. Finally, termination occurs when radicals combine to form stable, non-radical molecules in the lipid.

107. (A) Carbon 9
Humans lack the specific desaturase enzymes required to introduce a double bond beyond the ninth carbon atom from the carboxyl end of a fatty acid chain. Because of this biochemical limitation, linoleic acid and alpha-linolenic acid must be obtained through the diet. These essential fatty acids serve as critical precursors for the synthesis of long-chain polyunsaturated fatty acids and eicosanoids.

108. (C) Magnesium
Magnesium is a vital macro-mineral that acts as a critical cofactor for hundreds of enzymatic reactions, especially those involving the use of adenosine triphosphate. It binds to the phosphate groups of the molecule, stabilizing its structure and facilitating energy transfer. Additionally, magnesium plays an essential role

in regulating neuromuscular transmission and muscle contraction by modulating the activity of calcium channels.

109. (D) Phytic acid
The intestinal absorption of zinc is significantly influenced by several dietary factors. Phytic acid, which is found in whole grains and legumes, is the most potent inhibitor of zinc bioavailability. It binds tightly to zinc ions in the digestive tract, forming insoluble complexes that the human body cannot absorb. This inhibition is a major nutritional concern in populations with plant-based diets.

110. (C) Oat (Avena sativa)
Among the common cereal grains, oats are distinguished by their unique nutritional composition. They contain significantly higher levels of total protein and lipids compared to rice, maize, or wheat. These nutrients are concentrated primarily within the large germ and the outer layers of the grain. Furthermore, the protein quality of oats is superior due to a more balanced amino acid profile.

111. (B) 7S (vicilins) and 11S (legumins) globulins
The major storage proteins in legume seeds are globulins, which are categorized into two main fractions based on their sedimentation coefficients. The seven-S fraction, also known as vicilins, are trimeric proteins, while the eleven-S fraction, known as legumins, are hexameric proteins. These storage globulins provide a concentrated source of nitrogen and amino acids essential for the developing plant embryo.

112. (C) Isoamyl acetate
The characteristic and pleasant aroma of ripe bananas is primarily attributed to a specific volatile organic compound known as isoamyl acetate. This ester is biosynthesized during the ripening process and is widely used in the food industry to impart a banana flavor to various products. The production of this and other volatile esters is coordinated by the hormone ethylene.

113. (D) 1-aminocyclopropane-1-carboxylic acid (ACC)
Ethylene biosynthesis in higher plants follows a well-defined metabolic pathway. The immediate precursor to ethylene is one-aminocyclopropane-one-carboxylic acid, commonly abbreviated as ACC. This compound is produced from S-adenosylmethionine by the enzyme ACC synthase. In the final step of the pathway, ACC is converted directly into gaseous ethylene by the action of the enzyme ACC oxidase in the presence of oxygen.

114. (A) Molecular oxygen
Post-harvest enzymatic browning occurs when the enzyme polyphenol oxidase is released from cellular compartments and reacts with phenolic compounds in the presence of molecular oxygen. This reaction oxidizes the phenols into quinones, which then polymerize to form brown or black pigments called melanins. This process is common in cut or bruised fruits and is often controlled by limiting oxygen exposure.

115. (B) Delphinidin
Metabolic engineering has been successfully employed to produce “purple tomatoes” that are significantly enriched with delphinidin, a potent antioxidant anthocyanin. This was achieved by inserting regulatory genes from the snapdragon plant, which upregulate the endogenous flavonoid biosynthetic pathway in the tomato fruit. These anthocyanins provide enhanced nutritional value and may offer health benefits by protecting against various chronic diseases and inflammation.

116. (B) Flavan-3-ols
Catechins and epicatechins are prominent polyphenolic compounds found in tea and various fruits. Based on their molecular structure, they are classified as flavan-three-ols, a subclass of the flavonoid family. These compounds lack a carbonyl group at the four-position and possess a hydroxyl group at the three-position of the C-ring. They are recognized for their strong antioxidant properties and potential cardiovascular benefits.

117. (A) Condensed tannins
Condensed tannins are complex polyphenolic compounds found in sorghum and various legumes. They act as potent anti-nutritional factors by forming stable, indigestible complexes with dietary proteins and digestive enzymes. This high binding affinity is primarily due to strong hydrogen bonding and hydrophobic interactions. By precipitating these molecules, tannins drastically reduce the overall digestibility of proteins and the efficiency of the human digestion.

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136. (C) The presence of catalytic transition metals like copper and iron
Ascorbic acid is a highly sensitive molecule that can be easily oxidized into dehydroascorbic acid and further degraded during food storage. This process is significantly accelerated by exposure to heat, light, and alkaline conditions. Furthermore, the presence of trace amounts of transition metals, particularly copper and iron, acts as a powerful catalyst for the oxidative destruction of this essential vitamin.

137. (B) Cytokinin
Cytokinins are a class of plant hormones that are primarily recognized for their role in promoting cell division and growth. In the context of post-harvest physiology, cytokinins are considered potent inhibitors of ripening and senescence in fruits and vegetables. They function by maintaining the structural integrity of cellular membranes and delaying the degradation of chlorophyll and proteins, thus extending the shelf life.

138. (D) To reduce water loss (transpiration) and delay shrinkage
Coating fresh citrus fruits with a thin layer of food-grade wax is a common post-harvest practice. The primary physiological benefit of this application is the creation of a physical barrier that significantly reduces the rate of water loss through transpiration. By preventing moisture loss, the wax helps to maintain the fruit's turgidity and overall appearance, effectively delaying shrinkage and shriveling.

139. (C) β,β-carotene 15,15'-monooxygenase
Beta-carotene is a provitamin A carotenoid that is converted into active vitamin A within the human body. This biochemical process occurs primarily in the mucosal cells of the small intestine. A specific enzyme, known as beta-beta-carotene-fifteen-fifteen-prime-monooxygenase, catalyzes the oxidative cleavage of the central double bond of the molecule, yielding two molecules of retinal, which are then reduced to retinol.

140. (A) Isoflavones (e.g., genistein and daidzein)
Soybeans are the most significant dietary source of isoflavones, which are a specific subclass of flavonoid polyphenols. The primary isoflavones in soy include genistein, daidzein, and glycitein. These compounds are widely studied for their potential health benefits, as their chemical structure allows them to bind to estrogen receptors. This weak estrogenic activity has led to their classification as phytoestrogens in nutrition.

141. (C) Cottonseed
Gossypol is a toxic polyphenolic pigment naturally synthesized by plants in the cotton genus as a chemical defense against herbivores. It is found in concentrated amounts within the pigment glands of cottonseed. Because of its toxicity, which can affect the reproductive and cardiac systems, the use of cottonseed meal as a protein source for humans and non-ruminant animals requires specialized processing.

142. (A) P-2, Q-1, R-3, S-4
Different mycotoxins exhibit specific toxicodynamic profiles and target various organ systems in humans and animals. Aflatoxin B1 is primarily a hepatotoxin, while ochratoxin A targets the kidneys, causing nephrotoxicity. Zearalenone is known for its estrogenic effects on the reproductive system. Fumonisin B1 is associated with serious neurological disorders, such as leukoencephalomalacia, and has been linked to esophageal cancer.

143. (D) Atrophy and flattening of the intestinal villi
In individuals with celiac disease, the immune-mediated inflammatory response to gluten leads to severe structural damage in the small intestine. The primary pathological change is the progressive atrophy and flattening of the intestinal villi, combined with hyperplasia of the crypts. This reduction in the surface area for nutrient absorption results in malabsorption, nutritional deficiencies, and various gastrointestinal symptoms in patients.

144. (A) A non-digestible ingredient that stimulates beneficial gut bacteria
A prebiotic is defined as a non-digestible food ingredient that provides a health benefit to the host by selectively stimulating the growth or activity of beneficial bacteria in the colon. Unlike probiotics, which are live microorganisms, prebiotics are primarily specialized carbohydrates, such as fructooligosaccharides and inulin. They survive the journey through the stomach and small intestine to reach the microbiota.

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127. (A) Constipation and diverticular disease
Insoluble dietary fibers, such as cellulose and lignin, provide significant health benefits by increasing fecal bulk and stimulating the mechanical movement of chyme through the digestive system. These actions help to prevent chronic constipation and reduce the risk of developing diverticular disease. By maintaining regular bowel movements and lowering intestinal pressure, insoluble fibers contribute to the overall health of the colon.

128. (C) Adsorb at the air-water interface to form a viscoelastic film
The ability of proteins to form stable foams is a critical functional property in food applications such as meringues. This process depends on the protein's capacity to rapidly adsorb at the air-water interface and subsequently undergo partial denaturation. This structural change allows the protein molecules to form a cohesive and viscoelastic film around the air bubbles, which stabilizes the foam.

129. (A) The percentage of true absorbed nitrogen that is retained by the body
Biological value is a refined metric used to evaluate the nutritional quality of a protein source. It specifically measures the proportion of absorbed nitrogen that is actually retained by the body for growth and tissue maintenance. A high biological value indicates that the protein contains a balanced profile of all essential amino acids that closely matches the physiological requirements of humans.

130. (C) Only IV
Lipid rancidity involves the degradation of fats and oils through various chemical and enzymatic pathways. Hydrolytic rancidity is caused by the release of free fatty acids, while oxidative rancidity involves the formation of hydroperoxides from unsaturated fats. Ketonic rancidity results from the specific fungal metabolism of certain fatty acids. However, hydrolytic rancidity itself does not produce carcinogenic peroxides; these are oxidation products.

131. (D) The first double bond is at the third carbon from the methyl end.
The "omega" or "n" system for naming fatty acids indicates the position of the first double bond relative to the methyl end of the molecule. An omega-three fatty acid is defined as having its first double bond located between the third and fourth carbon atoms, counting from the methyl terminus. This structural feature is critical for its unique biological functions in humans.

132. (B) Copper (along with Zinc)
Superoxide dismutase is a vital antioxidant enzyme that catalyzes the dismutation of the highly reactive superoxide radical into oxygen and hydrogen peroxide. The cytosolic isoform of this enzyme is a metalloprotein that requires both copper and zinc as essential structural and catalytic cofactors. In this complex, copper is involved in the catalytic cycle, while zinc provides critical structural stability to the enzyme.

133. (C) Biliary obstruction preventing bile salt secretion
The digestion and absorption of dietary lipids are complex processes that fundamentally require the presence of bile salts in the small intestine. These salts facilitate the emulsification of fats and the formation of mixed micelles, which are necessary for lipid uptake. A biliary obstruction prevents the secretion of bile, leading to severely impaired fat absorption and the excretion of undigested lipids.

134. (D) Barley
Barley is a cereal grain distinguished by its high content of beta-glucan, a type of soluble dietary fiber. Clinical studies have proven that beta-glucan effectively lowers serum low-density lipoprotein cholesterol by forming a viscous gel in the digestive tract. This gel binds to bile acids, preventing their reabsorption and forcing the liver to use more cholesterol to synthesize new ones.

135. (A) Interaction of gliadin and glutenin to form a gluten network
The unique ability of wheat flour to form a viscoelastic dough is due to the presence of gluten proteins, specifically gliadins and glutenins. When the flour is hydrated and mechanically mixed, these proteins interact to form a complex, three-dimensional gluten network. This network provides the dough with the necessary elasticity to trap carbon dioxide gas during fermentation, allowing bread to rise.

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118. (A) Both A and R are true and R is the correct explanation of A.
Neurolathyrism is a severe neurodegenerative condition caused by the chronic consumption of the grass pea, Lathyrus sativus. The disease is triggered by a non-protein amino acid called beta-N-oxalyl-L-alpha-beta-diaminopropionic acid, or ODAP. This neurotoxin acts as a potent agonist at glutamate receptors in the central nervous system, leading to excitotoxicity and the permanent paralysis of the lower limbs.

119. (A) Histamine
Scombroid fish poisoning is a type of foodborne illness caused by the consumption of spoiled fish from families such as Scombridae. When these fish are stored at improper temperatures, bacteria convert the amino acid histidine into the biogenic amine histamine. High levels of histamine trigger pseudo-allergic reactions in humans, characterized by symptoms such as flushing, headaches, rashes, and gastrointestinal distress.

120. (C) Fructooligosaccharide (FOS)
Fructooligosaccharides are well-characterized prebiotics composed of short chains of fructose molecules. They are primarily linked by beta-two-one glycosidic bonds, often with a terminal glucose unit. Because human digestive enzymes cannot hydrolyze these specific linkages, these molecules reach the colon intact. There, they are selectively fermented by beneficial bacteria, such as Bifidobacterium, promoting a healthy balance of the gut microbiota.

121. (A) Inhibiting the absorption of cholesterol in the small intestine
Plant sterols and stanols are functional food components that effectively lower blood cholesterol levels. Because they possess a chemical structure very similar to cholesterol, they compete for space within the mixed micelles that facilitate fat absorption in the small intestine. This competition significantly reduces the amount of cholesterol that is absorbed into the bloodstream, leading to a decrease in total cholesterol.

122. (B) Antimicrobial agent and color fixative
Sodium nitrite is a versatile food additive commonly used in the preservation of processed meats like ham and bacon. It serves two primary functional roles: it acts as a potent antimicrobial agent by inhibiting the growth of Clostridium botulinum, and it functions as a color fixative. By reacting with myoglobin, it produces the characteristic pink-red color associated with cured meat products.

123. (D) Calorie
In the context of energy and nutrition, a calorie is a unit of measurement used to quantify the amount of thermal energy. Specifically, one calorie is defined as the exact amount of heat energy required to raise the temperature of one gram of pure water by one degree Celsius. This fundamental unit provides the basis for expressing the energy content of foods.

124. (B) 0.83 g / kg body weight / day
The Food and Agriculture Organization and World Health Organization have established a recommended dietary allowance for protein based on extensive nitrogen balance studies. For healthy adults, the suggested intake is approximately zero point eight three grams of high-quality protein per kilogram of body weight per day. This level is designed to meet the physiological requirements of nearly all healthy individuals.

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125. (C) A reducing sugar and a free amino group of a protein
The Maillard reaction is a complex non-enzymatic browning process that occurs during the heating or long-term storage of food products. This reaction is initiated by a chemical interaction between the carbonyl group of a reducing sugar and the free amino group of an amino acid or protein. This pathway leads to the formation of flavorful compounds and dark-colored pigments called melanoidins.

126. (D) The degree of crystallization and the proportion of amylose to amylopectin
The rate and extent of starch digestion in the human gastrointestinal tract are primarily determined by the physical and chemical structure of the starch granules. Key factors include the ratio of amylose to amylopectin, the degree of molecular crystallization, and the extent of physical entrapment within the food matrix. These parameters dictate whether the starch is rapidly hydrolyzed, slowly digested, or resistant.

145. (C) Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA)
Marine-derived nutraceuticals, particularly those found in cold-water fish oils, are highly valued for their rich content of long-chain omega-three polyunsaturated fatty acids. Specifically, eicosapentaenoic acid and docosahexaenoic acid are known for their critical roles in human health. These fatty acids are essential for maintaining cardiovascular health, supporting brain function, and modulating inflammatory responses throughout the body's various tissue systems.

146. (A) To impart a savory, "umami" flavor enhancement
Monosodium glutamate is the sodium salt of glutamic acid and is a widely used food additive. Its primary function in food processing and cooking is to enhance the savory or "umami" flavor of various dishes. MSG acts by stimulating specific glutamate receptors on the tongue, which intensifies the perception of meat-like or savory tastes without adding a significant salty flavor.

147. (B) The total volume of oxygen consumed and carbon dioxide produced
Indirect calorimetry is a standard clinical method used to measure an individual's basal metabolic rate. This technique estimates energy expenditure by quantifying the total volume of oxygen consumed and the amount of carbon dioxide produced by the body over a specific period. These respiratory measurements are then used to calculate the amount of energy released from the oxidation of macronutrients.

148. (D) Addition of energy and nutrient costs required for fetal growth and maternal tissue expansion
The recommended dietary allowance for energy and various nutrients is significantly increased during pregnancy to support the physiological changes in the mother and the development of the fetus. This adjustment accounts for the metabolic costs associated with the growth of new maternal tissues, such as the placenta and expanded blood volume, as well as the nutritional requirements for fetal growth.

149. (C) Sweetness and high solubility in cold water
Simple sugars, such as glucose and fructose, are characterized by their small molecular size, high solubility in cold water, and characteristic sweetness. These properties allow them to provide immediate energy and influence the flavor profile of foods. In contrast, complex polysaccharides like starch are large, insoluble molecules that do not possess sweetness and instead contribute to the texture and viscosity.

150. (A) A low Glycemic Index
A food that results in a slow and steady release of glucose into the bloodstream is characterized as having a low glycemic index. This sustained delivery of carbohydrates helps to maintain stable blood sugar levels and prevents the rapid insulin spikes associated with high GI foods. These physiological effects are particularly beneficial for weight management and reducing the long-term risk of diabetes.

151. (C) Soluble fibers form gels and ferment; insoluble fibers act as bulk
Soluble dietary fibers, such as pectin and gums, dissolve in water to form viscous gels and are readily fermented by colonic bacteria. In contrast, insoluble fibers like cellulose and lignin do not dissolve in water and pass through the digestive tract largely intact. While soluble fibers help regulate glucose and lipid levels, insoluble fibers primarily contribute to fecal bulk and regularity.

152. (D) Albumin
Albumin is the most abundant protein found in human blood plasma and plays several vital physiological roles. One of its primary functions is the maintenance and regulation of intravascular oncotic pressure. By exerting this osmotic force, albumin ensures that fluid remains within the circulatory system and prevents it from leaking into the surrounding tissues, which helps to maintain blood volume.

153. (A) Endogenous obligatory fecal nitrogen losses
True protein digestibility is a more accurate measure than apparent digestibility because it accounts for the nitrogen that is naturally excreted by the body, regardless of food intake. This includes endogenous nitrogen from sloughed-off intestinal cells, digestive enzymes, and mucus. By subtracting these obligatory losses from the total fecal nitrogen, the calculation provides a precise assessment of the nutrient's absorption.

154. (A) I, II and IV
Food lipids serve multiple critical functional roles in food processing and nutrition. They act

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as efficient heat transfer media during deep-fat frying and contribute to the desirable texture and flakiness of baked goods. Additionally, lipids are concentrated sources of energy and provide essential fatty acids. Phospholipids are particularly important as emulsifiers due to their unique amphiphilic structure, which stabilizes mixtures.

155. (B) Principal biochemical significance of consuming an optimal dietary ratio of Omega-6 to Omega-3 fatty acids is to balance the production of pro- and anti-inflammatory eicosanoids
Maintaining an optimal dietary ratio of omega-six to omega-three fatty acids is critical for regulating the body's inflammatory status. Omega-six fatty acids generally serve as precursors for pro-inflammatory eicosanoids, while omega-three fatty acids typically produce anti-inflammatory or less inflammatory mediators. A balanced intake ensures that these competing biochemical pathways are properly managed, promoting overall cardiovascular and systemic health in humans.

156. (D) Sodium
Sodium is the principal extracellular cation and plays a fundamental role in maintaining the body's overall fluid balance and osmotic pressure. It is essential for the generation and transmission of action potentials in nerve and muscle cells, allowing for efficient communication within the nervous system. Additionally, sodium helps to regulate blood volume and blood pressure through its interaction with the kidneys.

157. (A) Adequate micelle formation facilitated by dietary fats and bile salts
The intestinal absorption of fat-soluble vitamins, including A, D, E, and K, is closely linked to the digestion of dietary fats. This process fundamentally requires the formation of mixed micelles within the intestinal lumen, which is facilitated by the presence of bile salts and fatty acids. These micelles transport the vitamins to the surface of the enterocytes for uptake into the lymphatic system.

158. (C) Cereals are high in methionine but low in lysine, while pulses are high in lysine but low in methionine.
The nutritional profiles of cereals and pulses are naturally complementary, making their combination an ideal protein source for plant-based diets. Cereals are relatively rich in sulfur-containing amino acids like methionine but are deficient in lysine. Conversely, pulses are excellent sources of lysine but lack sufficient methionine. Consuming both ensures that all essential amino acids are provided in the proper proportions.

159. (A) Soluble in pure water and coagulable by heat
Based on the Osborne classification system for plant proteins, albumins are defined by their unique solubility properties. These proteins are readily soluble in pure water and are characterized by their ability to coagulate when exposed to heat. In many seeds, albumins function as enzymes or metabolic proteins rather than primary storage sources, and they often possess a high nutritional biological value.

160. (D) To provide water-soluble red, purple, or blue colors to attract seed dispersers
Anthocyanins are water-soluble vacuolar pigments that provide many fruits with their vibrant red, purple, or blue colors. From a biological perspective, these pigments serve as visual signals to attract various animals and insects that act as seed dispersers. Additionally, anthocyanins function as powerful antioxidants that protect the plant tissues from oxidative damage and environmental stressors such as ultraviolet radiation.

161. (B) Respiration and ethylene production
The climacteric peak represents a defining physiological event in the ripening of certain fruits, such as bananas and tomatoes. This phase is marked by a sudden and dramatic spike in both the rate of cellular respiration and the production of the gaseous hormone ethylene. This surge coordinates the rapid biochemical transformations that lead to changes in texture, color, and flavor profile.

162. (C) The action of cytochrome c oxidase in the mitochondrial electron transport chain
Controlled atmosphere storage effectively slows down the metabolic activity and ripening of fresh produce by significantly reducing the concentration of ambient oxygen. This environment fundamentally restricts the activity of cytochrome c oxidase, the final enzyme in the mitochondrial electron transport chain. By limiting the availability of oxygen for respiration, the overall rate of energy production and senescence is delayed significantly.

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163. (A) Iron, zinc, and provitamin A
Cassava is a vital staple crop in many tropical regions, but it is naturally low in several essential micronutrients. Metabolic engineering efforts have focused on enhancing its nutritional profile by significantly increasing the levels of iron, zinc, and provitamin A in the storage roots. These improvements aim to combat widespread malnutrition and specific deficiencies in populations that rely on it.

164. (D) Donate a hydrogen atom to neutralize a lipid peroxyl radical
Vitamin E, primarily in the form of alpha-tocopherol, is a potent fat-soluble antioxidant that protects biological membranes from oxidative damage. It functions by donating a hydrogen atom from its phenolic hydroxyl group to neutralize highly reactive lipid peroxyl radicals. This action effectively terminates the self-propagating chain reaction of lipid peroxidation, preventing the destruction of polyunsaturated fatty acids in the lipid bilayer.

165. (B) Iron and Zinc deficiency
Phytic acid is a common anti-nutritional factor found in the outer layers of cereal grains and seeds. Due to its strong ability to chelate divalent cations, it poses a significant risk for the development of mineral deficiencies. Populations that consume diets primarily based on unrefined cereals are particularly vulnerable to iron and zinc deficiency because these minerals become nutritionally unavailable.

166. (A) Both A and R are true and R is the correct explanation of A.
Raw or inadequately cooked kidney beans contain high concentrations of phytohaemagglutinin, a toxic type of protein known as a lectin. If consumed, this compound binds to the carbohydrate receptors on the surface of intestinal epithelial cells, causing significant damage and disrupting their normal function. This leads to acute gastroenteritis, characterized by severe nausea, vomiting, and diarrhea shortly after the ingestion.

167. (A) Tyramine
Tyramine is a naturally occurring biogenic amine found in aged or fermented foods such as cheese and wine. It normally undergoes rapid metabolism by the enzyme monoamine oxidase. However, in individuals taking MAO inhibitor medications, tyramine can accumulate to dangerous levels, causing the massive release of norepinephrine. This results in a severe hypertensive crisis, a potentially life-threatening elevation in blood pressure.

168. (C) It must be administered alive in adequate amounts to confer a health benefit to the host.
To be scientifically classified as a probiotic, a microbial strain must meet specific and rigorous criteria. It must be a live organism that, when administered in adequate amounts, confers a documented health benefit on the host. Furthermore, the strain should be clearly identified, safe for human consumption, and capable of surviving the transit through the acidic environment of the stomach.

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169. (D) Lower serum LDL cholesterol levels
Plant stanol esters are functional ingredients derived from phytosterols that are added to foods like margarine for their health benefits. Their primary role is to lower levels of low-density lipoprotein cholesterol in the blood. They achieve this by physically blocking the absorption of both dietary and biliary cholesterol from the small intestine, providing an effective dietary strategy for managing hypercholesterolemia.

170. (C) Citric acid
Citric acid is a versatile organic acid naturally found in citrus fruits and is widely used as a food additive. In the food industry, it serves several functions, acting as an acidulant to provide tartness, a chelating agent to stabilize minerals, and a flavor enhancer. It is particularly common in carbonated beverages where it helps to balance sweetness and acidity.

171. (B) 4 kcal/g
In the Atwater system of energy calorimetry, standardized physiological fuel values are used to estimate the metabolizable energy provided by different macronutrients. For digestible dietary carbohydrates, the general factor is established at four kilocalories per gram. This value represents the net energy available to the body after accounting for the efficiency of digestion and the energy lost during the metabolic process.

172. (C) 50 - 60%
Nutritional guidelines for a balanced diet recommend that a significant portion of total daily energy intake should come from

209. (C) ACC synthase
The biosynthesis of ethylene is a tightly regulated process that coordinates fruit ripening. A key regulatory step in this pathway is the conversion of S-adenosylmethionine into one-aminocyclopropane-one-carboxylic acid. This reaction is catalyzed by the enzyme ACC synthase, which is considered the rate-limiting enzyme in the entire pathway. The expression of this enzyme increases dramatically during the ripening of climacteric fruits.

210. (D) Extensive degradation of cellular proteins and destruction of cellular compartmentalization
Senescence in vegetables is the final stage of post-harvest life, characterized by a progressive decline in physiological and nutritional quality. During this phase, there is an extensive degradation of cellular proteins and a breakdown of compartmentalization within the cells. These biochemical changes lead to the loss of membrane integrity, the destruction of chlorophyll, and the eventual death of the plant tissue.

211. (A) Ferritin
To address global iron deficiency, scientists have used transgenic technology to increase the iron content in rice grains. A successful approach involves the endosperm-specific expression of ferritin, a specialized protein used by plants and animals for the safe storage of iron. By accumulating high levels of ferritin-bound iron in the edible portion of the rice, the crop becomes more nutritious.

212. (B) The shikimate and acetate-malonate pathways
The biosynthesis of the basic fifteen-carbon flavonoid skeleton in plants is a result of the convergence of two distinct metabolic pathways. The shikimate pathway provides the three-carbon bridge and one of the phenyl rings, while the acetate-malonate pathway contributes the other phenyl ring. This integration of pathways allows for the enormous diversity of flavonoid structures observed throughout the plant kingdom.

213. (C) Strong hydrogen bonding and hydrophobic interactions
Tannins are polyphenolic compounds that exert significant anti-nutritional effects by binding strongly to dietary proteins. This interaction is primarily driven by the formation of numerous hydrogen bonds between the hydroxyl groups of the tannins and the peptide bonds or amino acid side chains of the proteins. Hydrophobic interactions also contribute to the stability of these complexes, leading to protein precipitation.

214. (A) Both A and R are true and R is the correct explanation of A.
Cassava roots contain natural cyanogenic glycosides, specifically linamarin and lotaustralin, which can be hazardous if the roots are not processed correctly. When the plant tissue is damaged, these compounds are brought into contact with the enzyme linamarase, which catalyzes their hydrolysis. This reaction releases toxic hydrogen cyanide gas, which can cause acute poisoning in humans by inhibiting the mitochondrial electron transport.

215. (A) Allergies involve an immune response; intolerances are non-immunological
The fundamental distinction between a food allergy and a food intolerance lies in the involvement of the immune system. A true food allergy is an immune-mediated hypersensitivity reaction, often involving immunoglobulin E, that can occur even with trace amounts of food. In contrast, a food intolerance is a non-immunological metabolic issue that is often dose-dependent and results from enzymatic deficiencies.

216. (D) Complete synthesis of the body's daily requirement of Vitamin B_{12}
Probiotic bacteria provide many documented health benefits, including the modulation of the immune system, enhancement of the gut barrier, and exclusion of pathogens. However, while some gut bacteria can synthesize small amounts of certain vitamins, it is not a direct physiological effect of probiotics to provide the body's complete daily requirement of vitamin B_{12}, which must still come from diet.

217. (B) High solubility in lipids and organic solvents
Lycopene is an acyclic carotenoid composed entirely of carbon and hydrogen atoms, which imparts a highly hydrophobic nature to the molecule. Because of this structural feature, lycopene is completely insoluble in water but exhibits high solubility in lipids and various non-polar organic solvents. This lipophilic property is a key factor in its intestinal absorption and its distribution within cellular membranes.

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proteins, and intrinsic factor is essential for its absorption.

182. (C) Flaxseed (Linseed)
Flaxseed, also known as linseed, is exceptionally rich in lignans, which are a specific type of polyphenolic compound. The most abundant lignan in flaxseed is secoisolariciresinol diglucoside. When consumed, these compounds are converted by gut bacteria into enterolignans, which exhibit both antioxidant and weak phytoestrogenic activities. These properties have made flaxseed a popular functional food for cardiovascular and hormonal health.

183. (D) It disrupts secondary structures creating kinked conformations.
Prolamins, the major storage proteins in cereal grains, contain an unusually high concentration of the amino acid proline. The unique cyclic structure of the proline side chain prevents the formation of regular secondary structures like alpha-helices. Instead, it introduces numerous kinks and bends into the polypeptide chain, leading to a highly disordered and flexible conformation that influences the protein's overall solubility.

184. (C) Alkaloid
Capsaicin is the primary bioactive compound responsible for the intense pungency and heat associated with chili peppers. Biochemically, it is classified as a nitrogen-containing alkaloid and more specifically as a vanilloid. Capsaicin exerts its effects by binding to specific pain receptors, known as TRPV1 receptors, in the mouth and on the skin, which then transmit a sensation of heat.

185. (B) Cellular respiration rate
Non-climacteric fruits are distinguished by their ripening physiology, which does not involve a dramatic surge in metabolic activity. Unlike climacteric fruits, their cellular respiration rate and ethylene production remain relatively low and stable throughout the entire ripening process. While they may still undergo changes in sugar accumulation, pigment synthesis, and acidity, these events are not coordinated by a respiratory peak.

186. (D) The continuous loss of water vapor from the fresh produce, leading to wilting
Transpiration is a fundamental physiological process that occurs in all fresh produce after harvest. It involves the continuous loss of water vapor from the tissues through the stomata or other openings on the surface. This moisture loss is the primary cause of weight reduction, wilting, and shriveling, which significantly impacts the visual quality, texture, and overall market value of fruits.

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187. (A) Anthocyanins
The development of "purple tomatoes" through metabolic engineering focused on significantly increasing the content of anthocyanins within the fruit. By upregulating the biosynthetic pathway for these pigments, researchers were able to produce tomatoes with high levels of these powerful antioxidants. These compounds not only provide a unique color but also offer potential health benefits by reducing oxidative stress and inflammation.

188. (C) Hydrolyzable tannins
Hydrolyzable tannins are a specific class of polyphenolic compounds characterized by a central carbohydrate core, typically glucose, that is esterified with several molecules of phenolic acids like gallic acid. These tannins can be easily broken down into their constituent sugars and organic acids by the action of dilute acids or specific enzymes. They are found in various plant foods and nuts.

189. (A) Trypsin and chymotrypsin
Protease inhibitors are significant anti-nutritional factors found in many raw pulses and legumes. These small proteins function by binding tightly and specifically to the active sites of key pancreatic proteolytic enzymes, most notably trypsin and chymotrypsin. This binding effectively prevents the enzymes from hydrolyzing dietary proteins in the small intestine, leading to impaired nitrogen absorption and reduced overall growth rates.

190. (A) II, IV and V
Mycotoxins are toxic secondary metabolites produced by various fungal species, such as Aspergillus flavus, which contaminates crops under warm and humid storage conditions. Common mycotoxins like aflatoxins and patulin are chemically stable and can persist through

246. (B) Very low
The glycemic load of a food is a function of both its glycemic index and the total amount of carbohydrates present in a standard serving. Even if a food like a carrot has a relatively high glycemic index, its low carbohydrate density per portion will result in a very low glycemic load. This means that the actual impact on blood sugar is minimal.

247. (C) Lignin
Lignin is a highly complex and insoluble phenolic polymer that is found in the secondary cell walls of plants. It provides exceptional structural rigidity and resistance to mechanical stress and microbial attack. Unlike other dietary fibers, lignin is not a carbohydrate and is completely indigestible by both human enzymes and colonic bacteria. Its presence in the diet contributes primarily to fecal bulk.

248. (D) Iron ($Fe_{\{2+\}}$)
Myoglobin is a specialized metalloprotein found in muscle tissues that is responsible for the storage and transport of oxygen. Its structure features a porphyrin ring that rigidly complexes an essential trace element, iron, in its ferrous state. This iron ion is the specific site where oxygen binds reversibly, allowing muscle cells to maintain an internal oxygen reserve for use during activity.

249. (A) Protein Efficiency Ratio (PER)
The protein efficiency ratio is a biological assessment method used to determine the nutritional quality of protein sources. This technique typically involves a feeding trial with young, growing animals where the total weight gain is monitored over a specific period. The PER is then calculated by dividing the observed weight gain by the total weight of the protein consumed during the study.

250. (B) II, III and IV
The chemistry of food lipids involves several complex reactions that affect quality. Free transition metals act as catalysts that lower the activation energy for the initiation of oxidative rancidity. Saponification is the process of breaking down triglycerides into glycerol and fatty acid salts using a base. Antioxidants like vitamin E are critical because they donate hydrogen atoms to neutralize peroxy radicals.

251. (D) The methyl group ($-CH_{3)}$
In lipid biochemistry, the omega or "n" nomenclature is used to identify the position of double bonds in fatty acids. This system designates the position of the first double bond by counting the carbon atoms starting from the methyl group at the end of the chain. This classification is vital for understanding the biological roles and health impacts of different polyunsaturated fatty acids.

252. (B) Calcium
Calcium is a critical macro-mineral that serves both structural and regulatory functions in the human body. It is the primary mineral component of bones and teeth, providing the necessary strength and rigidity for the skeletal system. Beyond its structural role, calcium acts as a vital secondary messenger in cellular signal transduction, where it regulates processes such as muscle contraction and nerve impulses.

253. (C) A specific intact metalloporphyrin transporter (HCP1)
The intestinal absorption of heme iron is significantly more efficient than that of non-heme iron. This is because heme iron, which is found in animal-based foods, is absorbed as an intact metalloporphyrin complex. It utilizes a specific heme carrier protein on the surface of the enterocytes, bypassing the many dietary factors that often inhibit the absorption of ionic non-heme iron molecules.

254. (D) Endogenous anti-nutritional factors like trypsin inhibitors and lectins
The consumption of raw pulses and legumes is limited due to the presence of various endogenous anti-nutritional factors. These include protease inhibitors, such as trypsin inhibitors, and lectins like haemagglutinins, which can interfere with nutrient absorption and cause gastrointestinal distress. Fortunately, most of these harmful compounds are heat-labile and can be effectively inactivated through proper cooking and thermal processing.

255. (A) Globulins
While most cereal grains store their nitrogen primarily in the form of prolamins, oats are a unique exception in cereal biochemistry. The major storage protein fraction in oat grains consists of globulins, which are soluble in dilute salt solutions. These proteins have a more

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recirculation of bile salts from the ileum to the liver. As a result, the liver is forced to use its internal stores of cholesterol to synthesize new bile acids, leading to a reduction.

200. (B) Tryptophan
Tryptophan is one of the nine essential amino acids required for human health and is uniquely distinguished by its chemical structure. Its side chain contains an indole ring, which consists of a bicyclic system with a benzene ring fused to a pyrrole ring. This structural feature is critical for its role as a precursor for the synthesis of serotonin and niacin.

201. (A) It measures digestibility at the terminal ileum to avoid colonic interference
The digestible indispensable amino acid score represents a significant methodological improvement over the older PDCAAS system. Its primary advantage is that it measures the digestibility of individual amino acids at the terminal ileum, rather than assessing total nitrogen in the feces. This ileal approach more accurately reflects the actual amount of amino acids absorbed by the small intestine for metabolism.

202. (A) P-1, Q-3, R-2, S-4
Lipid degradation occurs through several distinct chemical pathways. Autoxidation is a free radical chain reaction often triggered by heat or metals. Photo-oxidation involves the excitation of oxygen by light and sensitizers. Hydrolytic rancidity is the enzymatic cleavage of ester bonds, releasing fatty acids. Thermal polymerization occurs at high temperatures, causing fatty acid chains to cross-link and form large molecular polymers.

203. (C) Linoleic acid
Linoleic acid is an essential eighteen-carbon omega-six fatty acid characterized by the presence of two double bonds. Because the human body cannot introduce double bonds beyond the ninth carbon from the carboxyl end, this fatty acid must be obtained through the diet. It serves as a vital component of cellular membranes and as a precursor for the synthesis of arachidonic acid.

204. (D) Promoting the conversion of hydroxyapatite to the harder, more decay-resistant fluorapatite in bones and teeth
Fluoride is a trace element that plays a critical role in dental and skeletal health. Its primary physiological function is to promote the conversion of hydroxyapatite, the main mineral in bones and teeth, into fluorapatite. This modified mineral is significantly harder and more resistant to the acid-induced demineralization caused by oral bacteria, thereby effectively helping to prevent dental caries.

205. (A) Hydrochloric acid
Achlorhydria is a clinical condition characterized by the complete absence of hydrochloric acid secretion from the parietal cells of the stomach. This condition significantly impairs the digestive process, particularly the breakdown of dietary proteins. Without stomach acid, the inactive enzyme pepsinogen cannot be converted into its active form, pepsin, which is essential for initiating the hydrolysis of protein molecules.

206. (C) Soybean (Glycine max)
Among the major pulse crops cultivated globally, the soybean is distinguished by its exceptionally high protein concentration. On a dry weight basis, it typically contains between thirty-six and forty percent protein, which is significantly more than other legumes like chickpeas or lentils. This high protein content, combined with a balanced amino acid profile, makes it a critical dietary resource.

207. (A) Dilute acid or alkali solutions
Based on the Osborne solubility classification system, cereal storage proteins are divided into several fractions. Glutelins are characterized by their insolubility in water, salt solutions, and aqueous ethanol. To selectively extract these proteins from the grain, dilute acid or alkali solutions are required. These solvents help to break the complex interchain bonds that hold the glutelin polymers together in the grain.

208. (B) Alliinase
The distinct flavor and pungent aroma of onions are produced by the action of the enzyme alliinase on odorless sulfur-containing precursors. These substrates, known as alk-enyl cysteine sulfoxides, are stored in the cytoplasm while the enzyme is sequestered in the vacuole. When the onion tissue is cut or crushed, the two components mix, triggering a rapid enzymatic reaction that releases volatiles.

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food processing. Chronic exposure to these toxins is a major health concern, as they are strongly linked to serious conditions like hepatocellular carcinoma.

191. (A) Mast cells and basophils
During the elicitation phase of an allergic reaction, subsequent exposure to a specific food allergen triggers a rapid immune response. The allergen molecules cross-link the immunoglobulin E antibodies that are already bound to the surface of mast cells and basophils. This cross-linking signals the cells to undergo degranulation, releasing a potent mixture of inflammatory mediators like histamine into the surrounding tissue.

192. (C) Human enzymes cannot cleave its specific β $(2_{\rightarrow}1)$ linkages.
Inulin is a complex carbohydrate composed of fructose units linked by specific beta-two-one glycosidic bonds. Its ability to serve as a prebiotic is fundamentally due to its resistance to human digestive enzymes. The human small intestine lacks the specific hydrolases required to cleave these beta-linkages. Consequently, inulin passes through the upper gastrointestinal tract undigested and reaches the colon to be fermented.

193. (A) Being fully saturated in the sterol ring (lacking double bonds)
Plant sterols and stanols are structurally similar compounds found in vegetable oils and grains. The fundamental chemical difference between them is that phytostanols are the fully saturated counterparts of phytosterols. This means that the stanol ring structure lacks the carbon-carbon double bonds present in the sterol ring. Both groups are used in functional foods for their ability to lower cholesterol.

194. (D) Yeasts and molds in acidic foods (pH < 4.5)
Sodium benzoate is a common synthetic food preservative that is most effective in acidic environments, typically at a pH below four point five. Its primary function is to inhibit the growth of various yeasts and molds in products such as fruit juices, carbonated beverages, and salad dressings. By disrupting the cellular metabolism of these microorganisms, it helps to prevent spoilage.

195. (C) 20 - 30%
The specific dynamic action, or thermic effect of food, is particularly high for proteins compared to other macronutrients. The biochemical processes involved in protein metabolism, including the synthesis of urea and the continuous turnover of body proteins, require a significant amount of energy. Consequently, approximately twenty to thirty percent of the total energy provided by ingested protein is dissipated as heat.

196. (C) To cover the needs of 97.5% of the specific healthy population
The recommended dietary allowance is established by adding a statistical margin of safety to the estimated average requirement. This safety margin, typically set at two standard deviations, is designed to account for the natural variability in nutrient requirements among individuals. By doing so, the RDA provides a target intake level that is sufficient to meet the physiological needs of ninety-seven point five percent.

197. (A) A homopolymer of N-acetylglucosamine linked by $\beta(1_{\rightarrow}4)$ bonds
Chitin is a major structural polysaccharide found in the exoskeletons of arthropods and the cell walls of fungi. It is a linear homopolymer composed of N-acetylglucosamine units joined by beta-one-four glycosidic bonds. Structurally, it is very similar to cellulose, but it contains nitrogen-containing groups that provide additional strength and rigidity, making it a critical component for biological protection and support.

198. (D) Intact, ungelatinized starch granules encased within whole cereal grains
The physical form of starch significantly influences its glycemic index. Intact and ungelatinized starch granules that are still encased within the fibrous cellular structures of whole grains have the lowest GI. In this form, the starch is physically protected from rapid enzymatic hydrolysis, leading to a much slower and more controlled release of glucose into the bloodstream after consumption.

199. (A) Bind bile acids to prevent recirculation and force new synthesis
Soluble dietary fibers exert a cholesterol-lowering effect primarily by increasing the viscosity of the intestinal contents and binding to bile acids. This prevents the normal reabsorption and

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218. (D) Hypersensitivity reactions and hyperactivity in children
Tartrazine, also known as FD and C Yellow five, is a synthetic azo dye used as a coloring agent in many processed foods and beverages. Its use is strictly regulated because it has been biochemically linked to hypersensitivity reactions in certain individuals, particularly those with aspirin sensitivity. In children, it has also been associated with increased levels of hyperactivity and behavioral issues.

219. (A) Thyroxine (T4)
The basal metabolic rate is the most important component of daily energy expenditure and is significantly regulated by the endocrine system. Specifically, the hormone thyroxine, produced by the thyroid gland, serves as the master regulator of metabolic activity in nearly all body tissues. By stimulating cellular respiration and protein turnover, circulating levels of thyroxine directly determine the overall speed of metabolism.

220. (C) The exact average (mean) requirement of the population group
The recommended dietary allowance for energy is established differently than the RDA for micronutrients. For vitamins and minerals, the RDA is set at a high level to cover the needs of almost all individuals. However, for energy, the RDA is set at the exact mean requirement of the population to prevent the risk of widespread obesity and related diseases.

221. (A) 2 and 10 monosaccharide units
Carbohydrates are structurally classified based on their degree of polymerization, which represents the number of monosaccharide units in the molecule. Oligosaccharides are typically defined as carbohydrates that contain between two and ten sugar units. Examples include common disaccharides like sucrose and lactose, as well as prebiotic compounds like fructooligosaccharides. Larger molecules with more than ten units are generally classified as polysaccharides.

222. (A) Pure glucose
The glycemic index is a relative ranking system that assesses how different carbohydrates affect blood sugar levels compared to a standard reference substance. Pure glucose is the most universally accepted standard, and it is assigned a glycemic index value of one hundred. By measuring the postprandial glucose response to a test food against this baseline, researchers can determine its GI.

223. (D) Low pH and high concentration of sucrose (greater than 55%)
High-methoxyl pectin requires specific environmental conditions to form a stable, three-dimensional gel network. This process only occurs in the presence of a low pH environment, which reduces the electrical repulsion between the pectin chains, and a high concentration of sucrose, typically greater than fifty-five percent. The sugar acts as a dehydrating agent, promoting the formation of hydrogen bonds between chains.

224. (B) Thermoreversible gelation and providing elasticity in food products
Gelatin is a functional protein produced through the partial thermal and chemical hydrolysis of collagen, a major structural protein found in animal connective tissues. In the food industry, gelatin is highly valued for its unique ability to undergo thermoreversible gelation. This property allows it to form elastic and stable gels at cold temperatures that melt upon heating, providing a desirable texture.

225. (C) 100
The biological value of a protein is a measure of the efficiency with which the body can utilize absorbed nitrogen for tissue synthesis. If a protein source provides all essential amino acids in the perfect proportion and is completely utilized without any urinary nitrogen loss, its theoretical biological value would be one hundred. This score indicates that the protein is high-quality.

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226. (C) I and III only
Saturated fatty acids like palmitic acid have no double bonds, allowing them to pack tightly. Polyunsaturated fatty acids, such as eicosapentaenoic acid, contain multiple double bonds and are essential for various biological functions. In contrast, oleic acid is a monounsaturated fatty acid that typically possesses a single cis-double bond in its natural state, which introduces a kink in the carbon chain.

227. (C) Delta-6 desaturase
In the metabolic pathways for essential fatty acids, alpha-linolenic acid and linoleic acid must compete for the same set of enzymes for their further processing. The most critical and rate-

limiting enzyme in these sequences is delta-six desaturase. This enzyme catalyzes the first step in the conversion of both precursors into their respective long-chain polyunsaturated fatty acid derivatives, such as EPA.

228. (D) Glucosinolates
Glucosinolates are a class of sulfur-containing secondary metabolites found in many plants, especially those in the Brassicaceae family. Some of their breakdown products, such as thiocyanates, act as potent goitrogens by competitively inhibiting the uptake of iodine by the thyroid gland. High consumption of these compounds, particularly in individuals with borderline iodine intake, can lead to the development of a goiter.

229. (A) Monoglutamates
Naturally occurring folates in food are primarily found as complex polyglutamate molecules. Before they can be absorbed into the bloodstream, they must undergo enzymatic cleavage in the brush border of the small intestine. An enzyme called folate conjugase hydrolyzes the extra glutamate residues, converting the molecules into the monoglutamate form, which is the only form that can be efficiently transported.

230. (C) Optimal balance of all essential amino acids
Quinoa is a highly nutritious pseudocereal that has gained global recognition for its exceptional protein quality. Unlike most traditional cereal grains, which are deficient in lysine, quinoa provides an optimal and balanced profile of all nine essential amino acids. This makes it a complete protein source, which is rare in the plant kingdom and particularly valuable for individuals on vegetarian diets.

231. (D) Trimer (7S complex)
Vicilin is one of the major storage globulins found in legume seeds and is characterized by a specific sedimentation coefficient of approximately seven-S. Structurally, these proteins typically exist as trimeric complexes, meaning they are composed of three individual polypeptide subunits. Vicilins provide an essential source of nitrogen and amino acids for the developing seedling and are generally low in sulfur.

232. (B) Avocado
The avocado is a unique tropical fruit that differs significantly from most other fruits in its biochemical composition. While most fruits store energy in the form of simple sugars, the avocado accumulates exceptionally high levels of lipids, primarily monounsaturated fatty acids like oleic acid, within its fleshy mesocarp. This high fat content provides a dense energy source and contributes to its creamy texture.

233. (C) Pectin methylesterase
The enzymatic degradation of pectin is a fundamental process that drives the softening of fruit during ripening. This pathway is biochemically initiated by the enzyme pectin methylesterase, which removes the methyl groups from the galacturonic acid residues in the pectin chain. This demethoxylation increases the accessibility of the polymer to other depolymerizing enzymes, such as polygalacturonase, which further break down the structure.

234. (D) Vital heat
During the post-harvest storage and handling of fresh vegetables, the produce continues to undergo cellular respiration. This metabolic process releases energy in the form of heat, which is referred to as vital heat. The accumulation of vital heat can accelerate the rate of deterioration and spoilage if it is not properly managed through adequate ventilation and cooling in the storage environment.

235. (A) Iron and Zinc
Pearl millet is a hardy staple crop in many arid regions and has been a primary target for biofortification efforts. Under the HarvestPlus initiative, specific varieties have been conventionally bred to accumulate significantly higher concentrations of iron and zinc in the endosperm. These biofortified millets are designed to provide a sustainable dietary solution to combat widespread mineral deficiencies in vulnerable populations.

236. (C) Singlet oxygen ($_1O2$)
Singlet oxygen is a highly reactive, non-radical form of oxygen that can cause significant oxidative damage to cellular components, particularly lipids and proteins. Carotenoids, such as beta-carotene and lycopene, are exceptionally efficient at neutralizing this species through a process known as physical quenching. During this interaction, the carotenoid absorbs the excess

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energy from the singlet oxygen, returning it to the ground state.

237. (B) Crushing tissue to mix enzyme and substrate
The effective detoxification of raw cassava is essential to ensure its safety for human consumption. This process relies on a crucial step where the plant tissue is physically crushed or grated. This action disrupts the cellular compartments, allowing the enzyme linamarase to mix with the cyanogenic glycosides. This enzymatic contact triggers the release of hydrogen cyanide, which can then be removed.

238. (A) II, III, I, IV
The toxicity of aflatoxin B1 begins with its ingestion and uptake by the liver. In the hepatic cells, it is enzymatically transformed by cytochrome P450 enzymes into a highly reactive intermediate called aflatoxin B1-eight-nine-epoxide. This metabolite then reacts with DNA to form guanine adducts, which can lead to mutations in critical genes such as the p53 tumor suppressor gene.

239. (D) Arachin (Ara h 1)
Arachin, also designated as Ara h one, is one of the primary storage proteins found in peanuts and is a major food allergen. It is recognized as one of the most potent triggers of immunoglobulin E-mediated type one hypersensitivity. Even minute amounts of this protein can cause severe allergic reactions, including life-threatening anaphylaxis, in sensitized individuals due to its stability.

240. (C) Bifidobacterium animalis and fructooligosaccharides
A synbiotic is defined by the synergistic combination of a probiotic microorganism and a prebiotic substrate that specifically promotes its growth. An excellent example of this relationship is the combination of Bifidobacterium animalis and fructooligosaccharides. The FOS serves as a fermentable fiber that is selectively utilized by the Bifidobacterium in the colon, enhancing its survival and metabolic activity to provide a health benefit.

241. (A) Brassicaceae (e.g., broccoli, cabbage)
Glucinates are a unique group of sulfur-containing secondary metabolites that are predominantly found in plants of the Brassicaceae family. This botanical group includes widely consumed vegetables such as broccoli, cabbage, kale, and Brussels sprouts. When these plants are consumed, the glucosinolates are broken down into various bioactive compounds, such as isothiocyanates, which are researched for their potential health-promoting and anti-cancer properties.

242. (C) Aspartic acid and Phenylalanine
Aspartame is a popular high-intensity artificial sweetener that is chemically classified as a dipeptide derivative. It is composed of the methyl ester of two amino acids: aspartic acid and phenylalanine. Because it is much sweeter than sucrose, it can be used in very small amounts to provide sweetness with minimal calories. However, its presence must be labeled for individuals with phenylketonuria.

243. (A) Precise variations in heat of combustion and digestibility for specific foods
Atwater specific factors represent a more refined method for estimating the metabolizable energy of foods compared to the general four-nine-four system. These factors account for the precise variations in the heat of combustion and the specific digestibility of macronutrients from different food sources. By using values tailored to individual commodities, this approach provides a more accurate assessment of the usable energy.

244. (C) The hydroxylation of proline and lysine during collagen synthesis
Vitamin C, or ascorbic acid, is an essential micronutrient that serves as a critical cofactor for several hydroxylation reactions in the body. Specifically, it is required by the enzymes prolyl hydroxylase and lysyl hydroxylase, which add hydroxyl groups to proline and lysine residues during the synthesis of collagen. This biochemical step is vital for the structural stability and strength of connective tissues.

245. (A) Heating in the presence of adequate water
Starch gelatinization is a fundamental physical process that occurs when starch granules are heated in the presence of adequate water. During this process, the granules absorb water and swell significantly, leading to the disruption of their crystalline structure and the leaching of amylose molecules. This transformation results in the formation of a viscous paste, which is essential for the texture of cooked starch.

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carbohydrates. Specifically, it is suggested that fifty to sixty percent of total calories be derived from complex carbohydrates, such as those found in whole grains and vegetables. This level provides a steady source of energy and essential dietary fiber for health.

173. (A) The spontaneous interconversion between the α and β anomeric forms of a sugar in aqueous solution
Mutarotation is a characteristic physicochemical property of many monosaccharides and disaccharides in aqueous solution. It refers to the spontaneous and reversible interconversion between the alpha and beta anomeric forms of a sugar. This process involves the temporary opening of the cyclic hemiacetal or hemiketal ring and results in a measurable change in the specific optical rotation of the solution.

174. (C) Reduced insulin demand and a lower risk of Type 2 diabetes
Adopting a diet primarily consisting of low glycemic index foods offers significant long-term health benefits for metabolic regulation. By providing a slow and steady release of glucose into the bloodstream, these foods minimize the overall demand for insulin secretion. This reduced physiological strain on the pancreas is associated with a lower risk of developing insulin resistance and type two diabetes.

175. (A) Butyrate
The bacterial fermentation of soluble dietary fibers in the colon produces various short-chain fatty acids, which play critical roles in intestinal health. Among these, butyrate is of particular importance as it serves as the primary energy source for the epithelial cells lining the colon, known as colonocytes. Butyrate also helps to regulate cell growth, reduce inflammation, and maintain barrier function.

176. (B) Secondary derived proteins
Secondary derived proteins are products formed through the progressive and partial hydrolysis of naturally occurring proteins. This group includes proteoses, peptones, and peptides, which are smaller and more soluble than the parent molecules. These substances are typically generated during the various stages of digestion in the gastrointestinal tract or through specific enzymatic and chemical processes used in food manufacturing.

177. (D) Lower digestibility and limiting essential amino acids
The protein digestibility corrected amino acid score for plant-based proteins is often lower than that for animal proteins due to two primary factors. First, many plant proteins are deficient in one or more essential amino acids, which limits their biological value. Second, the presence of various anti-nutritional factors and complex cell wall structures can reduce the overall intestinal digestibility.

178. (A) I, II, III
The rate at which food lipids undergo oxidative rancidity is primarily determined by their degree of unsaturation. Highly polyunsaturated oils, such as fish oil, possess many double bonds that are extremely vulnerable to free radical attack, leading to rapid degradation. Monounsaturated oils like olive oil oxidize at a slower rate, while fully saturated fats are the most stable.

179. (B) Desaturation and elongation
Linoleic acid $(18{:}2, \omega-6)$ is converted to arachidonic acid $(20{:}4, \omega-6)$ through alternating desaturation and elongation reactions. Desaturase enzymes introduce additional double bonds, while elongase enzymes add two-carbon units to extend the fatty acid chain. Arachidonic acid is an important precursor of eicosanoids, including prostaglandins, thromboxanes, and leukotrienes, which regulate inflammation, immunity, and other physiological processes.

180. (B) Potassium
Potassium is the principal intracellular cation and is essential for maintaining the body's normal physiological environment. It plays a critical role in regulating intracellular fluid volume and maintaining the resting membrane potential across cell membranes. This is vital for the proper functioning of excitable tissues, such as nerves and muscles, and for the overall regulation of cellular metabolism and enzyme activity.

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181. (A) Vitamin B_{12}
Atrophic gastritis is a condition characterized by the chronic inflammation and thinning of the stomach lining, which leads to a severe reduction in the secretion of hydrochloric acid and intrinsic factor. This environment drastically impairs the bioavailability of vitamin B12, as stomach acid is required to release the vitamin from food

balanced amino acid profile compared to the prolamins found in wheat or maize, contributing to higher protein quality.

256. (C) β-carotene
Beta-carotene is a vibrant yellow-orange carotenoid pigment found abundantly in carrots and various other vegetables. It is the most important provitamin A precursor in the human diet, as it can be enzymatically cleaved to yield two molecules of retinal. Beyond its role in vitamin A synthesis, beta-carotene also functions as a potent antioxidant, protecting cells from oxidative damage caused by radicals.

257. (B) Transmembrane receptors located on the endoplasmic reticulum
In the ripening of climacteric fruits, the hormone ethylene acts as a master chemical signal. At the molecular level, ethylene initiates these changes by binding to specific transmembrane receptors. These receptors are primarily located on the membrane of the endoplasmic reticulum within the plant cells. This binding event triggers a signal transduction cascade that activates the expression of numerous ripening-related genes in the plant.

258. (C) Phase transition of membrane lipids from a fluid liquid-crystalline state to a solid gel state
Chilling injury is a significant post-harvest disorder that occurs in tropical and subtropical fruits when they are exposed to low, non-freezing temperatures. The primary biochemical event associated with this condition is the phase transition of the cellular membrane lipids. The membranes shift from a flexible, liquid-crystalline state to a rigid, solid-gel state, which leads to structural damage and metabolic dysfunction.

259. (D) Phytoene synthase
The successful development of "Golden Rice" required the introduction of multiple genes to enable the biosynthesis of beta-carotene in the rice endosperm. A critical step in this engineered pathway was the introduction of the gene for phytoene synthase, typically derived from maize or daffodils. This enzyme catalyzes the first committed step in carotenoid synthesis, allowing the plant to produce the precursor.

260. (A) Ortho-diphenolic structures that stabilize unpaired electrons
The antioxidant activity of phenolic compounds is strongly influenced by their specific molecular structure. Compounds that possess an ortho-diphenolic configuration exhibit the highest capacity for scavenging free radicals. This structure allows the molecule to effectively stabilize the unpaired electrons of radicals through the formation of stable intramolecular hydrogen bonds and resonance. This structural feature is a key determinant of overall efficacy.

261. (C) Trypsin
Raw soybeans contain two main families of protease inhibitors that act as significant anti-nutritional factors. The Kunitz trypsin inhibitor is a specific protein that binds tightly to the pancreatic enzyme trypsin, effectively neutralizing its ability to hydrolyze dietary proteins. This inhibition can lead to poor nitrogen utilization and pancreatic hypertrophy. These inhibitors must be destroyed by heat treatment before consumption.

262. (A) P-2, Q-3, R-1, S-4
Anti-nutritional factors in food exert their negative effects through various biochemical mechanisms. Phytic acid acts by chelating essential minerals, while trypsin inhibitors block the activity of specific pancreatic enzymes. Haemagglutinins, or lectins, bind to the intestinal lining and disrupt nutrient absorption. Cyanogenic glycosides are hazardous because their enzymatic degradation releases hydrogen cyanide, which inhibits the mitochondrial electron transport chain.

263. (D) Glutamine into glutamic acid
Celiac disease involves a complex immune response to gluten peptides that are rich in proline and glutamine. A key enzyme in this process is tissue transglutaminase, which is released during intestinal inflammation. This enzyme modifies the gluten peptides by converting specific glutamine residues into negatively charged glutamic acid. This modification significantly increases the binding affinity of the peptides to the immune system.

264. (A) β-glycosidic bonds (e.g., $\beta(2\rightarrow1)$ in inulin)
Prebiotics are specialized dietary fibers that provide health benefits by reaching the colon undigested. This resistance to upper gastrointestinal digestion is due to the unique

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in crops. This technology works by introducing double-stranded RNA molecules that trigger a natural cellular process to silence or downregulate a specific target gene. By reducing the expression of enzymes that degrade desirable nutrients or produce unwanted compounds, researchers can significantly enhance the nutritional profile of crops.

284. (A) Flavonols
Quercetin is one of the most abundant and widely studied polyphenolic compounds in the human diet. Based on its chemical structure, it is classified as a member of the flavonol subclass within the flavonoid family. Quercetin is found in many fruits, vegetables, and grains, and it is highly regarded for its potent antioxidant, anti-inflammatory, and potential cardiovascular protective effects in humans.

285. (C) Proteinaceous protease inhibitors and lectins
The thermal treatment of raw legumes is an essential processing step required to ensure their safety and nutritional quality. Cooking or boiling these seeds effectively denatures and inactivates several heat-labile anti-nutritional factors. Specifically, proteinaceous compounds such as protease inhibitors and lectins are destroyed by heat, which significantly improves the overall digestibility of the proteins and prevents harmful physiological reactions.

286. (A) The renal system (kidneys)
Ochratoxin A is a toxic mycotoxin produced by several species of Aspergillus and Penicillium fungi, which commonly contaminate cereals and coffee beans. This toxin is highly stable and can persist through many food processing steps. Its most severe health impact is on the renal system, where it causes progressive nephrotoxicity and has been linked to the development of kidney cancer.

287. (B) Lactase-phlorizin hydrolase
Lactose intolerance is a metabolic condition caused by a deficiency in the enzyme lactase-phlorizin hydrolase, which is located in the brush border of the small intestinal mucosa. This enzyme is responsible for hydrolyzing the disaccharide lactose into its constituent monosaccharides, glucose and galactose. Without sufficient enzyme activity, undigested lactose enters the colon where it is fermented by bacteria, causing digestive symptoms.

288. (C) Acetate
The fermentation of dietary fiber by the diverse community of bacteria in the human colon produces several short-chain fatty acids. While all of these metabolites contribute to health, acetate is produced in the largest molar proportion. Once formed, acetate is absorbed into the bloodstream and transported to various tissues, where it serves as a substrate for energy metabolism and lipid synthesis.

289. (D) Promoting beneficial changes in body composition (reducing adiposity)
Conjugated linoleic acid is a group of positional and geometric isomers of linoleic acid that are found naturally in dairy products and meat from ruminant animals. CLA has been the subject of extensive nutritional research due to its potential health benefits. Some studies suggest that CLA may promote beneficial changes in body composition by reducing adiposity and increasing lean mass.

290. (A) Silicon dioxide
Silicon dioxide, also known as silica, is a common food additive that is classified as an anti-caking agent. Its primary functional role is to prevent the formation of lumps in powdered food products, such as table salt, spices, and non-dairy creamers. By absorbing excess moisture and improving the flow properties of the particles, it ensures that the products remain easy to use.

NODIA

291. (B) 10%
The thermic effect of food represents the increase in metabolic rate that occurs after the ingestion of a meal. It accounts for the energy required for the digestion, absorption, and initial processing of nutrients. In a healthy adult with a balanced diet, the thermic effect of food typically constitutes approximately ten percent of the total daily energy expenditure.

292. (D) 15.0 mg/day
To calculate the recommended dietary allowance for a nutrient with low bioavailability, the physiological requirement must be adjusted by the expected absorption rate. If the daily requirement for absorbed iron is one point five milligrams and only ten percent of dietary iron is absorbed, the total intake must be ten times the requirement. Therefore, the RDA would be fifteen milligrams.

274. (B) Only III
The chemical and physical properties of lipids are determined by the structure of their fatty acid chains. Saturated fatty acids have high melting points, while cis-double bonds lower the melting point by introducing kinks. Phospholipids are amphiphilic molecules with a phosphate head group. However, it is incorrect to say that trans-double bonds eliminate the hydrocarbon chain; they simply create linear.

275. (A) Linoleic acid and Alpha-linolenic acid
In human nutrition, there are two primary parent essential fatty acids that cannot be synthesized by the body and must be obtained from the diet. These are linoleic acid, an omega-six fatty acid, and alpha-linolenic acid, an omega-three fatty acid. These two molecules serve as the foundational precursors for the synthesis of all other long-chain polyunsaturated fatty acids and mediators.

276. (C) Glutathione peroxidase
Selenium is an essential trace element that exerts its biological functions primarily as a component of the amino acid selenocysteine. This unique amino acid is found within the active site of several important antioxidant enzymes, most notably glutathione peroxidase. This enzyme plays a critical role in protecting cells from oxidative damage by catalyzing the reduction of harmful hydrogen peroxide and organic hydroperoxides.

277. (D) Passive paracellular diffusion and an active transcellular pathway via TRPM6/7 channels
The intestinal absorption of magnesium is a complex process that occurs through two distinct physiological pathways. A significant portion of magnesium uptake occurs through passive paracellular diffusion, which is driven by the concentration gradient. Additionally, there is an active transcellular pathway that is mediated by specific ion channels, known as TRPM six and TRPM seven, located on the surface of enterocytes.

278. (C) Severe burns or prolonged starvation
Nitrogen balance is a measure of the body's overall protein status. A negative nitrogen balance occurs when the amount of nitrogen excreted by the body exceeds the amount ingested. This physiological state is associated with periods of severe physical stress, such as major burns, prolonged starvation, or serious infections. In these conditions, the body breaks down its own muscle tissue.

279. (D) Salt-soluble 11S globulin with disulfide bonds
Legumin is one of the primary storage proteins found in legume seeds and is classified as an eleven-S globulin. Structurally, it is a large and complex hexameric protein that is held together by both non-covalent interactions and specific disulfide bonds between its subunits. Legumin is insoluble in pure water but can be extracted using dilute salt solutions, following Osborne's rules.

280. (C) Clove
Eugenol is a volatile phenolic compound that is the primary component of the essential oil extracted from cloves. It is responsible for the characteristic strong and pungent aroma associated with this spice. Beyond its role as a flavor compound, eugenol possesses significant antimicrobial, analgesic, and antioxidant properties, which have led to its use in various traditional medicinal practices.

281. (A) ACC oxidase
The final step in the biosynthesis of the plant hormone ethylene is the oxidative conversion of its immediate precursor, one-aminocyclopropane-one-carboxylic acid. This specific biochemical reaction is catalyzed by the enzyme ACC oxidase. The activity of this enzyme is highly regulated and increases dramatically during the ripening of climacteric fruits, facilitating the sudden burst of ethylene production that coordinates the ripening process.

282. (C) Ethylene
Climacteric fruits undergo a series of rapid and coordinated biochemical changes as they ripen. This process is initiated by a sudden surge in the rate of cellular respiration, which is tightly coupled with the massive production of the gaseous hormone ethylene. Ethylene acts as the master chemical signal that triggers the expression of genes responsible for changes in fruit texture.

283. (D) Silencing a specific target gene that degrades a desired compound
Metabolic engineering using RNA interference is a powerful strategy for modifying specific traits

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2017

19. The malate-oxaloacetate shuttle is primarily involved in the indirect transfer of what across the chloroplast envelope?
(A) Adenosine triphosphate (ATP)
(B) Ribulose-1,5-bisphosphate
(C) Reducing equivalents (NADPH/NADH)
(D) Starch granules

2013

20. Consider the following statements about Cytosolic Sucrose Biosynthesis:
I. Sucrose-phosphate synthase (SPS) catalyzes the formation of sucrose-6-phosphate.
II. Fructose-2,6-bisphosphate acts as a regulatory metabolite inhibiting cytosolic FBPase.
III. SPS activity is downregulated by protein phosphorylation in the dark.
IV. Sucrose synthase is the primary enzyme for sucrose synthesis in active mesophyll.
Which of the above statements are INCORRECT?
(A) IV only
(B) I and IV
(C) II and IV
(D) I, III and IV

2014

21. Which enzyme catalyzes the primary regulatory step in plastidial starch biosynthesis?
(A) Starch synthase
(B) Starch branching enzyme
(C) Phosphoglucomutase
(D) ADP-glucose pyrophosphorylase (AGPase)

2003

22. During seed development, photoassimilates are converted into storage lipids primarily in which subcellular compartment?
(A) Oleosomes (lipid bodies)
(B) Vacuole
(C) Peroxisome
(D) Amyloplasts

2008

23. The action spectrum of photosynthesis typically mirrors the absorption spectrum of which pigment group?
(A) Anthocyanins
(B) Betalains
(C) Chlorophylls
(D) Flavonoids

2017

24. What is the biochemical consequence of the distinct lipid composition, highly enriched in monogalactosyldiacylglycerol (MGDG), of the thylakoid membrane?
(A) It facilitates structural curvature necessary for grana stacking
(B) It renders the membrane completely impermeable to non-polar molecules
(C) It prevents the lateral migration of intrinsic protein complexes
(D) It actively pumps protons without the requirement for solar light

NODIA

2004

25. Consider the following statements about pigment biosynthesis:
I. Glutamate is the initial precursor for chlorophyll biosynthesis.
II. Protoporphyrin IX is a common intermediate for both chlorophyll and heme.
III. Phycobilins are closed tetrapyrroles similar to chlorophyll.
IV. Carotenoids are derived from the isoprenoid pathway.
V. The insertion of magnesium into protoporphyrin IX commits the pathway to chlorophyll synthesis.
Which of the above statements are correct?
(A) I, II, IV and V
(B) I, III and IV
(C) II, III, IV and V
(D) I, II and V

2006

26. In the context of light harvesting, what prevents excessive energy transfer and minimizes photo-oxidative damage under high light?
(A) Increased photorespiration rates to dissipate excitation energy
(B) Non-photochemical quenching (NPQ) via the xanthophyll cycle
(C) Complete degradation of all existing chlorophyll a molecules
(D) Uncoupling of the ATP synthase complex from the membrane

2018

27. The Kok clock model explains the mechanism of which specific functional component of the chloroplast?
(A) The cyclic electron transport pathway
(B) The activation of Rubisco by Rubisco activase
(C) The S-state transitions of the Oxygen-Evolving Complex
(D) The diurnal opening of stomata in CAM plants

293. (A) All chiral centers are perfectly inverted
D-glucose and L-glucose are enantiomers, which means they are non-superimposable mirror images of each other. The fundamental stereochemical difference between these two molecules is that the configurations around all chiral carbon atoms are perfectly inverted. While D-glucose is the naturally occurring and biologically active form in human metabolism, L-glucose cannot be utilized as an energy source by most organisms.

294. (C) Ensure sustained glucose availability over the event duration
Consuming low glycemic index foods before engaging in prolonged aerobic exercise provides a significant physiological advantage for athletes. Because these foods are digested and absorbed slowly, they ensure a sustained and steady release of glucose into the bloodstream over several hours. This prevents rapid insulin spikes and provides a consistent energy source, which helps to maintain endurance during the event.

295. (D) Pancreatic lipase
High-viscosity soluble dietary fibers exert several beneficial health impacts by altering the physical state of the intestinal contents. These fibers form a thick gel that can physically hinder the interaction between dietary triglycerides and the enzyme pancreatic lipase. By slowing the rate of fat hydrolysis and subsequent absorption, these fibers effectively lower the level of postprandial lipemia in the blood.

296. (A) Desmosine
Elastin is a unique structural protein found in connective tissues that provides exceptional elasticity to organs like the skin and lungs. This property is biochemically derived from the presence of specialized cross-links between the elastin molecules. These cross-links involve the formation of desmosine and isodesmosine, which are unique amino acid derivatives created from the condensation of multiple lysine residues.

297. (B) The weight loss observed in a non-protein control group
The net protein ratio is a biological method for evaluating protein quality that offers a significant improvement over the protein efficiency ratio. While the PER only measures the weight gain of animals fed the test protein, the NPR also includes a control group fed a non-protein diet. This allows for the precise accounting of the weight loss in the control group.

298. (D) The bis-allylic methylene carbon located between two double bonds
In the chemistry of polyunsaturated fatty acids, the most vulnerable site for the initiation of oxidative rancidity is the bis-allylic methylene carbon. This specific carbon atom is located between two carbon-carbon double bonds. The hydrogen atoms attached to this carbon are relatively easy to abstract because the resulting lipid radical is stabilized by resonance with the adjacent double bond systems.

299. (A) Eicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA)
The omega-three index is a clinical biomarker used to assess an individual's long-term intake of heart-healthy fats. It represents the combined percentage of two specific long-chain polyunsaturated fatty acids, eicosapentaenoic acid and docosahexaenoic acid, in the membranes of red blood cells. A higher index value is strongly associated with a reduced risk of cardiovascular disease and overall improved metabolic health.

300. (B) Carbonic anhydrase
Zinc is an essential trace element that serves as a critical structural and catalytic cofactor for many enzymes. One of its most vital roles is in the function of carbonic anhydrase, which regulates blood pH by catalyzing the reversible conversion of carbon dioxide and water into bicarbonate. A deficiency in zinc severely impairs the activity of this specific enzyme.

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CHAPTER 07
Photosynthesis

2022

1. Which wavelength range defines Photosynthetically Active Radiation (PAR)?
(A) 200 to 400 nm
(B) 400 to 700 nm
(C) 500 to 800 nm
(D) 700 to 900 nm

2025

2. What is the primary structural feature distinguishing grana from stroma thylakoids in chloroplasts?
(A) Grana are unstacked and highly enriched in Photosystem I
(B) Grana lack chlorophyll entirely
(C) Grana are stacked and predominantly contain Photosystem II
(D) Grana are located in the outer chloroplast envelope

2010

3. Which characteristic differentiates chlorophyll a from chlorophyll b?
(A) Chlorophyll a contains copper, whereas chlorophyll b contains a magnesium ion
(B) Chlorophyll a has a C7 methyl group; chlorophyll b has a formyl group
(C) Chlorophyll a lacks a phytol tail, whereas chlorophyll b possesses a long tail
(D) Chlorophyll a absorbs in the green spectrum; chlorophyll b absorbs in the yellow

2008

4. Resonance energy transfer within Light-Harvesting Complexes (LHCs) occurs primarily because:
(A) Electrons are physically transported between the adjacent pigment molecules
(B) ATP is hydrolyzed to provide the necessary chemical activation energy
(C) Protons are actively pumped across the specific thylakoid membrane surface
(D) Energy is transferred non-radiatively via dipole-dipole interactions

2019

5. Match the components of Photosystem II with their specific functional roles.

List I : (Components)
P. D1/D2 proteins
Q. Oxygen-Evolving Complex
R. Pheophytin
S. Plastoquinone Qa

List II : (Roles)
1. Primary electron acceptor
2. Core reaction center heterodimer
3. Water oxidation and proton release
4. Tightly bound quinone electron carrier

(A) P-2, Q-3, R-1, S-4
(B) P-3, Q-2, R-4, S-1
(C) P-1, Q-4, R-2, S-3
(D) P-4, Q-1, R-3, S-2

2022

6. Which statement INCORRECTLY describes the structural organization of Photosystem I (PSI)?
(A) The reaction center core contains P700
(B) The core complex contains iron-sulfur centers
(C) PSI is predominantly located in the appressed regions of the grana
(D) PSI accepts electrons from plastocyanin

2001

7. During linear electron transport, the cytochrome b6f complex directly facilitates which process?
(A) Transfer of electrons from plastoquinol to plastocyanin
(B) Reduction of $NADP^+$ to NADPH
(C) Oxidation of water molecules
(D) Synthesis of cyclic AMP

2014

8. What is the primary physiological advantage of cyclic photophosphorylation?
(A) It generates equivalent stoichiometric amounts of ATP and NADPH
(B) It significantly enhances the metabolic rate of photorespiration
(C) It actively oxidizes excess NADPH molecules within the stroma
(D) It produces ATP without the concomitant reduction of $NADP^+$

NODIA

2017

9. According to the chemiosmotic theory, ATP synthesis via the CF0-CF1 complex is driven directly by:
(A) The physical movement of high-energy electrons through the cytochrome complex
(B) A proton motive force consisting of a pH gradient and electrical potential
(C) The active oxidation of malate within the specialized bundle sheath cells
(D) The direct transfer of high-energy phosphate groups from the molecule PEP

2004

10. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Light-induced proton pumping into the thylakoid lumen causes magnesium ions to move from the lumen into the stroma.
Reason (R) : The efflux of magnesium ions compensates for the electrical charge imbalance created by proton influx.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2003

11. Which enzyme catalyzes the first committed step of the Calvin-Benson cycle?
(A) Phosphoglycerate kinase activity
(B) Fructose-1,6-bisphosphatase activity
(C) Sedoheptulose-1,7-bisphosphatase activity
(D) Ribulose-1,5-bisphosphate carboxylase/oxygenase

2004

12. The oxygenase activity of Rubisco leads directly to the formation of which two molecules?
(A) One molecule of 3-phosphoglycerate and one molecule of 2-phosphoglycolate
(B) Two molecules of 3-phosphoglycerate
(C) One molecule of malate and one molecule of oxaloacetate
(D) Two molecules of glyceraldehyde-3-phosphate

2009

13. How does the ferredoxin-thioredoxin system regulate Calvin cycle enzymes?
(A) By phosphorylating the metabolic enzymes at specific serine residues
(B) By reducing enzyme disulfide bonds to sulfhydryl groups in the light
(C) By increasing the overall concentration of cytosolic calcium ions
(D) By oxidizing key regulatory enzymes during active photosynthesis

2004

14. In C4 plants, spatial separation of initial carbon fixation and the Calvin cycle is accommodated by which anatomical feature?
(A) Spongy mesophyll
(B) Kranz anatomy
(C) Epidermal trichomes
(D) Guard cell chloroplasts

2007

15. Consider the following statements regarding Crassulacean Acid Metabolism (CAM):
I. Stomata open at night to allow carbon dioxide entry.
II. Malate is stored in the vacuole during the night.
III. PEP carboxylase is highly active during the day.
Which of the above statements are correct?
(A) I and II
(B) III only
(C) II and III
(D) I, II and III

NODIA

2025

16. Which three organelles are strictly required for the complete photorespiratory (C_2) cycle?
(A) Chloroplast, peroxisome, mitochondrion
(B) Chloroplast, mitochondrion, Golgi apparatus
(C) Peroxisome, endoplasmic reticulum, vacuole
(D) Nucleus, mitochondrion, chloroplast

2023

17. In the context of leaf gas exchange, what term describes the ratio of CO_2 assimilated to water lost via transpiration?
(A) Respiratory quotient
(B) Water-use efficiency (WUE)
(C) Quantum yield
(D) Stomatal conductance

2019

18. The triose phosphate/phosphate translocator (TPT) facilitates a strict counter-exchange of triose phosphates for which molecule?
(A) Sucrose
(B) Malate
(C) ATP
(D) Inorganic phosphate (Pi)

(B) Maximization of nitrogen use efficiency in soil
(C) Avoidance of highly saline soil concentrations
(D) Adaptation to low-light understory conditions

2005

39. During photorespiration, the conversion of two molecules of glycine to one molecule of serine releases:
(A) Oxygen and water
(B) Carbon dioxide and ammonia
(C) ATP and NADPH
(D) Nitrate and nitrite

2005

40. Consider the following statements about C4 photosynthesis:
I. It requires less ATP per CO_2 fixed than C3 photosynthesis.
II. It effectively concentrates CO_2 around Rubisco.
III. PEP carboxylase has a higher affinity for HCO^{3-} than Rubisco has for CO_2.
IV. It virtually eliminates photorespiration under normal conditions.
Which of the above statements is INCORRECT?
(A) I only
(B) II and III
(C) IV only
(D) I and IV

2025

41. The export of triose phosphates from the chloroplast via the TPT is heavily dependent on the cytosolic concentration of:
(A) Orthophosphate (Pi)
(B) Starch
(C) Sucrose
(D) Fructose

2015

42. Which intracellular shuttle mechanism primarily balances the ATP/NADPH ratio between the chloroplast and the cytosol?
(A) The triose phosphate shuttle
(B) The malate-aspartate shuttle
(C) The glycerol-3-phosphate shuttle
(D) The malate-oxaloacetate shuttle

2004

43. Fructose-2,6-bisphosphate (F2,6BP) serves as an essential regulatory molecule in plant cells by:
(A) Activating Rubisco directly within the stroma
(B) Inhibiting FBPase and activating PPi-PFK
(C) Triggering the opening of stomata in the dark
(D) Reversing the catalytic action of sucrose synthase

2021

44. The allosteric activation of ADP-glucose pyrophosphorylase (AGPase) during plastidial starch biosynthesis is primarily achieved by which metabolite?
(A) Inorganic phosphate (Pi)
(B) Fructose-6-phosphate
(C) 3-Phosphoglycerate (3-PGA)
(D) Malate

2024

45. Match the biochemical pathway with its primary localization in the plant cell.
List I : (Pathways)
P. Synthesis of storage triacylglycerols
Q. Initial carboxylation in C4 plants
R. Decarboxylation of glycine
S. Starch accumulation
List II : (Localizations)
1. Mitochondria
2. Plastids (Amyloplasts/Chloroplasts)
3. Endoplasmic reticulum
4. Mesophyll cytosol
(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-2, Q-1, R-4, S-3
(D) P-1, Q-2, R-3, S-4

2004

46. Storage proteins in developing seeds are typically accumulated and stored within:
(A) Protein storage vacuoles (PSVs)
(B) Peroxisomes
(C) Mitochondria
(D) The apoplast

2008

47. Which intrinsic property of a pigment molecule determines its specific absorption spectrum?
(A) The physical mass of the molecule
(B) The arrangement of conjugated double bonds and substituent groups
(C) The concentration of the pigment in the thylakoid
(D) The ambient temperature of the leaf

2018

48. In the structural organization of a chloroplast, what connects distinct grana stacks together?
(A) Tonoplasts
(B) Plasmodesmata

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2007

28. Which of the following best describes the role of phylloquinone (A1) in Photosystem I?
(A) It serves as the ultimate electron acceptor from ferredoxin
(B) It binds directly to the oxygen-evolving complex
(C) It provides the proton gradient across the membrane
(D) It transfers electrons from P700 to the iron-sulfur clusters

2011

29. During the Z-scheme of electron transport, electrons pass from Photosystem II to Photosystem I. Which carrier is the immediate electron donor to PSI?
(A) Plastoquinone
(B) Plastocyanin
(C) Cytochrome f
(D) Ferredoxin

2023

30. Select the correct sequence of electron transfer in the linear electron transport chain.
(A) PSII → Plastoquinone → Plastocyanin → Cytochrome b6f → PSI
(B) PSII → Plastoquinone → Cytochrome b6f → Plastocyanin → PSI
(C) PSI → Plastocyanin → Cytochrome b6f → Plastoquinone → PSII
(D) PSII → Plastocyanin → Plastoquinone → Cytochrome b6f → PSI

2002

31. The Mehler reaction (pseudocyclic electron transport) produces which potentially damaging byproduct that must be detoxified?
(A) Hydrogen peroxide
(B) Superoxide radical
(C) Carbon monoxide
(D) Ozone

2003

32. What drives the conformational change in the CF1 unit of ATP synthase to release newly synthesized ATP?
(A) The rotation of the gamma subunit driven by proton flux
(B) The binding of NADPH
(C) The absorption of a blue light photon
(D) The phosphorylation of the epsilon subunit

NODIA

2023

33. State 1 to State 2 transitions in thylakoids are regulated primarily by the phosphorylation of which component?
(A) Rubisco
(B) Cytochrome f
(C) ATP synthase
(D) Light-Harvesting Complex II (LHCII)

2005

34. In the reduction phase of the Calvin-Benson cycle, 3-phosphoglycerate is first converted to 1,3-bisphosphoglycerate. Which molecule provides the phosphate for this reaction?
(A) ATP
(B) NADPH
(C) Phosphoenolpyruvate
(D) Fructose-1,6-bisphosphate

2009

35. Arrange the following steps of Rubisco activation in the correct structural order.
I. Binding of substrate RuBP
II. Carbamylation of specific lysine residue
III. Binding of magnesium ion
IV. Action of Rubisco activase to remove inhibitory sugar phosphates
(A) IV, II, III, I
(B) I, II, III, IV
(C) IV, III, II, I
(D) II, III, I, IV

2024

36. Which Calvin cycle enzyme is insensitive to light-dependent regulation via the ferredoxin-thioredoxin system?
(A) Fructose-1,6-bisphosphatase
(B) Triose phosphate isomerase
(C) Sedoheptulose-1,7-bisphosphatase
(D) Phosphoribulokinase

2001

37. In NADP-ME type C4 plants, which enzyme is responsible for the decarboxylation of malate in the bundle sheath cells?
(A) PEP carboxylase
(B) Pyruvate, phosphate dikinase
(C) NAD-malic enzyme
(D) NADP-malic enzyme

2025

38. The primary evolutionary driver for the development of the CAM pathway in specific plant lineages was most likely:
(A) Minimization of water loss in arid environments

chemical structure of their glycosidic bonds. Human digestive enzymes are only capable of hydrolyzing alpha-linkages. Consequently, prebiotics containing beta-linkages, such as the beta-two-one bonds in inulin, cannot be broken down and instead serve as substrate.

265. (B) Beta-sitosterol
Beta-sitosterol is one of the most common plant sterols found in various vegetable oils, nuts, and seeds. Due to its chemical structure, which is very similar to that of cholesterol, it acts as a potent nutraceutical. It functions by selectively inhibiting the intestinal absorption of cholesterol, thereby helping to lower total and low-density lipoprotein cholesterol levels in the bloodstream and improving heart health.

266. (C) Molds in baked bakery goods (e.g., bread)
Propionic acid and its calcium or sodium salts are widely used as food additives in the baking industry. Their primary functional role is to serve as antimicrobial preservatives that specifically inhibit the growth of molds and certain bacteria. By preventing the development of mold on bread and other baked goods, propionates help to extend the shelf life and safety of these products.

267. (D) The liver
While skeletal muscle accounts for a large portion of body mass, it is relatively less metabolically active at rest compared to internal organs. In a healthy, resting adult, the liver is the single most metabolically active organ, contributing the highest total percentage to the daily resting energy expenditure. This high energy demand is due to its numerous essential metabolic functions.

268. (B) 97.5%
The recommended dietary allowance is a statistical target designed to cover the nutritional needs of nearly all healthy individuals in a specific population. It is calculated by taking the estimated average requirement and adding two standard deviations of the requirement. This mathematical approach ensures that the resulting RDA value is sufficient for ninety-seven point five percent of the target population.

269. (C) Being highly branched with $\alpha(1\rightarrow6)$ every 8-12 units
Glycogen and amylopectin are both branched polysaccharides composed of glucose units. However, they differ significantly in their degree of branching. Glycogen, the primary energy storage molecule in animals, is much more highly branched than amylopectin, which is found in plants. In glycogen, alpha-one-six branches occur frequently, typically every eight to twelve glucose units, providing a more compact structure.

270. (A) High levels of intact dietary fiber and cellular structures
The glycemic index of starchy foods is heavily influenced by the physical state of the food matrix. The presence of intact dietary fiber and intact cellular structures acts as a physical barrier that slows the access of digestive enzymes to the starch granules. Consequently, foods that maintain their natural cellular integrity have a much lower glycemic index than refined powders.

271. (D) The rate of nutrient absorption in the gut system
Soluble dietary fibers, such as gums and mucilages, significantly alter the physiological properties of the intestinal contents. By dissolving in water, they form a highly viscous, gel-like matrix that slows the movement of nutrients within the lumen. This increased viscosity directly reduces the rate at which sugars, lipids, and other nutrients are absorbed through the intestinal wall into the circulatory system.

272. (A) Bind and transport iron safely in the blood plasma
Transferrin is a critical plasma protein that plays a central role in the regulation of iron homeostasis in the body. Its primary physiological function is to bind ferric iron with high affinity and transport it safely through the bloodstream to various tissues, such as the bone marrow and liver. This transport mechanism ensures that iron is available for essential synthesis.

273. (C) Amino acid score (ratio of the limiting amino acid to the reference pattern)
The protein digestibility corrected amino acid score is the standard method for evaluating protein quality. It is calculated by multiplying the true fecal digestibility of the protein by its amino acid score. The amino acid score is the ratio of the first limiting amino acid in the test protein to the amount of that same amino acid in a reference pattern.

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(C) Stroma lamellae (unstacked thylakoids)
(D) Microtubules

2019

49. Phycobilins are characteristic accessory pigments predominantly found in which groups of organisms?
(A) Cyanobacteria and red algae
(B) Higher plant and ferns
(C) Brown algae and diatoms
(D) Fungi and non-photosynthetic parasitic plants

2009

50. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : The inner membrane of the chloroplast envelope is highly permeable to a wide variety of ions and metabolites.
Reason (R) : The inner membrane contains specific transporters that regulate the movement of metabolites.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2021

51. The primary function of the Oxygen-Evolving Complex (OEC) relies heavily on a cluster of which specific transition metal ions?
(A) Copper
(B) Iron
(C) Manganese
(D) Zinc

2008

52. Within the cytochrome b6f complex, which component is essential for the bifurcation of electron flow during the Q-cycle?
(A) Rieske iron-sulfur protein
(B) Ferredoxin
(C) Plastoquinone
(D) Pheophytin

2021

53. The operation of the Q-cycle in the cytochrome b6f complex directly results in:
(A) The reduction of oxygen to water
(B) The synthesis of NADPH in the lumen
(C) The release of carbon dioxide
(D) The translocation of additional protons across the thylakoid membrane

2013

54. In the linear electron transport chain, what is the theoretical ratio of ATP produced per pair of electrons transferred, assuming standard stoichiometry?
(A) 0.5
(B) 1.5
(C) 2.5
(D) 4.0

2025

55. Consider the following statements regarding the CF0-CF1 ATP synthase:
I. CF0 is embedded in the thylakoid membrane and forms a proton channel.
II. CF1 protrudes into the stroma and contains the catalytic sites for ATP synthesis.
III. It operates independent of any proton gradient.
Which of the above statements are correct?
(A) I and II
(B) I only
(C) II and III
(D) I, II and III

NODIA

2024

56. The transition from State 2 back to State 1 in thylakoids occurs when:
(A) Plastoquinone pool becomes completely reduced
(B) LHCII is dephosphorylated by a specific phosphatase
(C) Stomata close abruptly during the transition
(D) The plant is exposed exclusively to far-red light

2010

57. During the regeneration phase of the Calvin-Benson cycle, five molecules of a 3-carbon sugar are rearranged to form:
(A) Three molecules of ribulose-5-phosphate
(B) One molecule of glucose
(C) Three molecules of ribulose-1,5-bisphosphate
(D) Five molecules of oxaloacetate

2002

58. The catalytic mechanism of Rubisco involves the intermediate formation of:
(A) A carbanion bound to zinc
(B) A free radical localized on iron
(C) An acyl-enzyme intermediate
(D) An enediolate bound to magnesium

2017

59. Which Calvin cycle enzyme is absolutely dependent on the cleavage of its regulatory disulfide bond for catalytic activation?
(A) Phosphoglycerate kinase
(B) Sedoheptulose-1,7-bisphosphatase
(C) Ribose-5-phosphate isomerase
(D) Triose phosphate isomerase

2009

60. Consider the following statements about C4 photosynthesis subtypes:
I. NADP-ME subtypes decarboxylate malate in chloroplasts of bundle sheath cells.
II. NAD-ME subtypes decarboxylate aspartate-derived malate in mitochondria of bundle sheath cells.
III. PCK subtypes utilize phosphoenolpyruvate carboxykinase for decarboxylation.
IV. All three subtypes lack Kranz anatomy.
Which of the above statements is INCORRECT?
(A) I and II
(B) III
(C) IV
(D) I, II and III

2024

61. In CAM plants, the accumulation of malic acid in the vacuum during the night causes the cellular sap to become:
(A) Highly alkaline
(B) Isotonic with the external environment
(C) Chemically inert
(D) Highly acidic

2014

62. Which key intermediate connects the chloroplast and the peroxisome during the C_2 oxidative photosynthetic carbon cycle?
(A) Glycolate
(B) Glyoxylate
(C) Serine
(D) Glycerate

2017

63. From an energetic perspective, what is the major disadvantage of photorespiration in C_3 crops?
(A) It generates excess toxic levels of ATP
(B) It prevents light absorption by chlorophyll
(C) It loses fixed carbon and consumes energy
(D) It irreversibly destroys the Rubisco enzyme

2014

64. The primary limitation preventing TPT from exporting unlimited amounts of triose phosphate into the cytosol is:
(A) The absolute requirement for imported orthophosphate (Pi)
(B) The rapid degradation of TPT by cytosolic proteases
(C) The lack of ATP in the intermembrane space
(D) The continuous closure of stomata

2013

65. Consider the following statements regarding intracellular integration:
I. The dicarboxylate translocator transports malate and a-ketoglutarate.
II. The chloroplast inner envelope is freely permeable to NADH.
III. The malate-oxaloacetate shuttle moves reducing equivalents without moving the cofactors themselves.
IV. Cytosol-organelle metabolite exchange is crucial for nitrogen assimilation.
V. Starch degradation products cannot leave the chloroplast.
Which of the above statements are INCORRECT?
(A) I and III
(B) II and V
(C) III and IV
(D) I, IV and V

2014

66. Covalent regulation of Sucrose-Phosphate Synthase (SPS) typically involves:
(A) Cleavage by a specific protease in response to calcium
(B) Phosphorylation by an SPS-kinase, which generally inactivates the enzyme
(C) Methylation of a crucial lysine residue
(D) Attachment of a ubiquitin tag

2006

67. The synthesis of transient starch in the chloroplast during the day directly utilizes which substrate?
(A) ADP-glucose
(B) UDP-glucose
(C) GDP-mannose
(D) CDP-diacylglycerol

2009

68. The primary biochemical pathway converting sucrose into storage lipids in seeds requires carbon flow through:
(A) The Calvin cycle
(B) Glycolysis and fatty acid biosynthesis
(C) The pentose phosphate pathway solely
(D) The shikimate pathway

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2003

69. Why does the action spectrum of photosynthesis not perfectly overlap the absorption spectrum of isolated chlorophyll a?
(A) Because chlorophyll a only functions in the dark
(B) Because accessory pigments transfer energy to the reaction center
(C) Because isolated chlorophyll a degrades upon light exposure
(D) Because the spectrum measures leaf respiration rates

2014

70. Select the correct sequence of intermediates in the synthesis of chlorophyll a.
(A) Glutamate → Protoporphyrin IX → Mg-protoporphyrin IX → Protochlorophyllide → Chlorophyll a
(B) Protoporphyrin IX → Glutamate → Protochlorophyllide → Mg-protoporphyrin IX → Chlorophyll a
(C) Glutamate → Mg-protoporphyrin IX → Protoporphyrin IX → Protochlorophyllide → Chlorophyll a
(D) Mg-protoporphyrin IX → Glutamate → Protoporphyrin IX → Protochlorophyllide → Chlorophyll a

2019

71. The highly organized structure of the chloroplast inner membrane relies on specific galactolipids. Which is the most abundant lipid in the thylakoid membrane?
(A) Phosphatidylcholine
(B) Monogalactosyldiacylglycerol (MGDG)
(C) Digalactosyldiacylglycerol (DGDG)
(D) Sulfoquinovosyldiacylglycerol (SQDG)

2001

72. Which component represents the primary antenna complex for Photosystem II in higher plants?
(A) Light-Harvesting Complex II (LHCII)
(B) Core complex I
(C) Phycobilisome
(D) Cytochrome b6f

2015

73. Which of the following defines the primary role of the D1 protein in Photosystem II?
(A) It binds the reaction center chlorophyll and redox cofactors
(B) It serves as a light-harvesting accessory pigment component
(C) It forms a channel for proton leakage through membranes
(D) It functions as a direct ATP synthase enzymatic complex

2024

74. Which process does NOT occur within the functional dynamics of Photosystem I?
(A) Absorption of far-red light (> 680 nm)
(B) Generation of a strong reductant
(C) Splitting of water to release molecular oxygen
(D) Oxidation of plastocyanin

2007

75. Arrange the structural components of the chloroplast envelope from the outside in.
I. Stroma
II. Inner envelope membrane
III. Outer envelope membrane
IV. Intermembrane space
(A) III, IV, II, I
(B) I, II, IV, III
(C) IV, III, II, I
(D) III, II, IV, I

NODIA

2015

76. Plastoquinone exists in a pool within the thylakoid membrane and its primary physiological function is to:
(A) Transfer electrons and protons from PSII to the cytochrome b6f complex
(B) Mediate energy transfer between antenna pigments
(C) Catalyze the formation of ATP from ADP
(D) Transport malate across the tonoplast

2016

77. The PGR5-dependent pathway is primarily responsible for which aspect of photosynthetic electron transport?
(A) Linear electron flow from PSII to PSI
(B) Cyclic electron transport around Photosystem I
(C) Reduction of water at the OEC
(D) Maintenance of stroma pH in the dark

2023

78. Which statement is correct concerning the proton motive force generated during light reactions?
(A) It consists solely of an electrical gradient ($\Delta\Psi$)
(B) It consists solely of a chemical gradient (ΔpH)
(C) It is dominated by the ΔpH component in steady-state
(D) It is oriented such that the stroma is highly

(A) It is perfectly homogeneous with PSII and PSI
(B) It exhibits extreme lateral heterogeneity
(C) It contains only lipids and lacks proteins
(D) It is physically connected to the nucleus

2012

119. In chlorophyll molecules, the tetrapyrrole ring is coordinated to a central magnesium ion. What role does the long phytol tail play?
(A) It acts as the primary light-absorbing chromophore
(B) It anchors the chlorophyll molecule into the hydrophobic core of the thylakoid lipid bilayer
(C) It donates electrons to plastoquinone
(D) It enzymatically splits water

2014

120. Which of the following describes the core principle of resonance energy transfer in antenna pigments?
(A) Exciton transfer occurs from long to short wavelengths
(B) Exciton transfer requires physical collision of pigments
(C) Energy moves downhill toward the reaction center
(D) It strictly depends on the hydrolysis of ATP

2009

121. The role of tyrosine-Z (Tyr-Z) in Photosystem II is to:
(A) Absorb light directly from the environment
(B) Bind the manganese cluster structurally
(C) Reduce plastoquinone
(D) Carry electrons between the OEC and $P680^+$

2009

122. Within the Photosystem I reaction center, P700 is a specialized dimer of:
(A) Chlorophyll a molecules (specifically, a heterodimer of Chl a and Chl a')
(B) Chlorophyll b molecules
(C) Pheophytin molecules
(D) Plastoquinone molecules

2001

123. During the Q-cycle of the cytochrome b6f complex, how many molecules of plastoquinol are oxidized to result in the net translocation of four protons?
(A) 1
(B) 2
(C) 4
(D) 8

2014

124. What environmental condition primarily triggers a shift toward cyclic electron transport around PSI?
(A) High ratio of NADPH to $NADP^+$ in the stroma
(B) Extremely low light intensity
(C) Abundant atmospheric CO_2
(D) Complete absence of oxygen

2023

125. Which statement accurately details the mechanism of proton translocation by the ATP synthase?
(A) Protons diffuse passively through the lipid bilayer
(B) Protons travel through CF0, driving rotor rotation
(C) Protons are pumped against their gradient by ATP
(D) Protons bind to beta subunits to form phosphate bonds

2006

126. State transitions (State 1 $<\!\!\rightarrow$ State 2) represent a short-term regulatory mechanism primarily designed to:
(A) Protect the leaf from severe freezing damage
(B) Balance the excitation energy distribution evenly between PSII and PSI
(C) Increase the rate of photorespiration
(D) Repair heat-damaged Rubisco

2022

127. The regeneration phase of the Calvin cycle involves the enzyme transketolase, which structurally transfers:
(A) Two-carbon units between sugar phosphates
(B) Three-carbon units between sugar phosphates
(C) A single phosphate group from ATP to ribulose-5-phosphate
(D) Electrons from NADPH to 1,3-bisphosphoglycerate

2016

128. Rubisco's affinity for CO_2 relative to O2 dictates the baseline rate of photorespiration. In C3 plants at 25°C, what approximate percentage of Rubisco reactions involve oxygenation?
(A) Less than 1%
(B) About 20-25%
(C) About 50%
(D) Over 80%

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2003

88. In terms of crop productivity trade-offs, C4 plants generally outperform C3 plants under which environmental conditions?
(A) Cool temperatures and high moisture
(B) Dense, shaded forest understories
(C) Environments with extremely high atmospheric CO_2 concentrations
(D) High light intensity, high temperature, and water limitation

2002

89. If the triose phosphate/phosphate translocator (TPT) is chemically inhibited, what is the most immediate metabolic consequence in the chloroplast?
(A) Carbon dioxide fixation accelerates significantly
(B) Starch hyper-accumulation and stromal Pi depletion
(C) The chloroplast rapidly exports sucrose
(D) The thylakoid membranes dissolve

2004

90. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : The malate-oxaloacetate shuttle is indispensable for maintaining redox balance between the chloroplast and cytosol.
Reason (R) : The inner chloroplast envelope completely lacks a transporter for intact NAD^+ or NADH.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2011

91. Sucrose is the predominant sugar transported in the phloem of most plants because it is:
(A) Highly reactive and easily reduced
(B) A non-reducing sugar that is chemically stable
(C) A monosaccharide that readily diffuses
(D) Synthesized exclusively in the roots

2008

92. In the pathway of cytosolic sucrose biosynthesis, what is the role of UDP-glucose pyrophosphorylase?
(A) It synthesizes UDP-glucose from glucose-1-phosphate and UTP
(B) It splits sucrose into glucose and fructose
(C) It attaches phosphate to fructose-6-phosphate
(D) It dephosphorylates sucrose-6-phosphate

2002

93. Transient starch synthesized in leaves during the day is primarily broken down during the night to supply the plant with:
(A) Cellulose
(B) Neutral sugars for export
(C) ATP directly
(D) Amino acids

2001

94. The accumulation of storage proteins in seeds is highly dependent on nitrogen availability. These proteins are largely translated on the:
(A) Smooth endoplasmic reticulum
(B) Rough endoplasmic reticulum
(C) Inner mitochondrial membrane
(D) Chloroplast envelope

2011

95. Consider the following statements about plant pigments:
I. Chlorophyll b functions mainly to broaden the spectrum of light absorbed.
II. Carotenoids serve exclusively as structural components of the membrane.
III. Phycobilisomes are located in the stroma of higher plant chloroplasts.
Which of the above statements is correct?
(A) I only
(B) II only
(C) I and II
(D) II and III

2005

96. Which feature characterizes the biochemical anatomy of the stroma?
(A) It contains Calvin cycle enzymes, DNA, and ribosomes
(B) It contains high densities of PSII complexes
(C) It lacks any soluble proteins
(D) It maintains a constant acidic pH of 4.0

2022

97. Beta-carotene functions in photoprotection by directly quenching which harmful state?
(A) Triplet state of chlorophyll and singlet oxygen
(B) Ground state chlorophyll
(C) Superoxide dismutase
(D) Plastoquinol

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2021

98. Light-Harvesting Complexes (LHCs) are physically attached to the photosystems. The predominant LHC associated with PSII is a:
(A) Monomer
(B) Hexamer
(C) Nonamer
(D) Trimer

2017

99. The core of the Oxygen-Evolving Complex (OEC) transitions through five distinct oxidation states (S0 to S4). Which state releases molecular oxygen?
(A) S0
(B) S4
(C) S2
(D) S3

2012

100. Consider the following statements about Photosystem I:
I. It functions as a plastocyanin-ferredoxin oxidoreductase.
II. The core contains two large subunits, PsaA and PsaB.
III. It exclusively drives linear electron transport.
IV. Its primary electron acceptor is A0 (a specific chlorophyll a molecule).
Which of the above statements are correct?
(A) I, II and IV
(B) I, II and III
(C) II, III and IV
(D) I, III and IV

2024

101. During Z-scheme electron transport, how many photons must be absorbed globally by both photosystems to extract 4 electrons from water and produce 1 molecule of O_2?
(A) 4
(B) 8
(C) 12
(D) 16

2021

102. What is the fate of ferredoxin during cyclic photophosphorylation?
(A) It reduces $NADP^+$ to NADPH via FNR
(B) It donates electrons to the plastoquinone pool
(C) It irreversibly binds to molecular oxygen
(D) It transfers electrons directly to water

2002

103. The energy required to synthesize one molecule of ATP via the chloroplast CF0-CF1 complex requires the translocation of approximately how many protons?
(A) 1 to 2
(B) 3 to 4.7
(C) 8 to 10
(D) 14 to 16

2008

104. Which light condition predominantly induces a transition to State 2, where LHCII migrates to unstacked regions?
(A) Excess Far-Red light (preferentially exciting PSI)
(B) Complete darkness
(C) Excess Red light (preferentially exciting PSII)
(D) Ultraviolet B radiation

2007

105. Consider the following statements regarding the Calvin-Benson cycle:
I. Three molecules of ATP are consumed per CO_2 fixed.
II. Two molecules of NADPH are consumed per CO_2 fixed.
III. The carboxylation phase requires no direct input of ATP or NADPH.
IV. The reduction phase yields 3-phosphoglycerate.
V. The regeneration of RuBP consumes ATP.
Which of the above statements is INCORRECT?
(A) I
(B) III
(C) IV
(D) V

NODIA

2017

106. In what functional state must the active site lysine of Rubisco be for catalytic competence?
(A) Carbamylated and bound to Mg^{2+}
(B) Phosphorylated
(C) Methylated
(D) Acetylated

2006

107. The light-dependent modulation of stromal pH (increasing from approx 7.0 to 8.0) directly enhances the activity of:
(A) Rubisco and fructose-1,6-bisphosphatase
(B) ATP synthase degradation
(C) Proteases in the vacuole
(D) Sucrose synthase in the cytosol

2021

108. In the C4 Hatch-Slack pathway, the initial carbon acceptor in the mesophyll cytosol is:
(A) Phosphoenolpyruvate
(B) Ribulose-1,5-bisphosphate
(C) Oxaloacetate
(D) Malate

2006

109. Which of the following is a primary characteristic of Phase III of Crassulacean Acid Metabolism (CAM) during the day?
(A) Stomata are wide open allowing mass CO_2 influx
(B) Malate is rapidly synthesized and stored in the vacuole
(C) The Calvin cycle is completely inactive
(D) Stomata close, malate decarboxylates, and CO_2 rises

2024

110. Which enzyme in the photorespiratory cycle resides in the peroxisome and produces hydrogen peroxide?
(A) Glycolate oxidase
(B) Catalase
(C) Hydroxypyruvate reductase
(D) Serine hydroxymethyltransferase

2009

111. The energetic cost (ATP equivalent) to fix one molecule of CO_2 is higher in C4 plants than in C3 plants. What is the generally accepted ratio of ATP/NADPH required per CO_2 in a standard NADP-ME C4 plant?
(A) 2 ATP : 2 NADPH
(B) 3 ATP : 2 NADPH
(C) 4 ATP : 2 NADPH
(D) 5 ATP : 2 NADPH

2002

112. Which mechanism prevents a futile cycle of simultaneous starch synthesis and degradation in the chloroplast?
(A) Synthetic enzymes activation and degradative inhibition
(B) Strict spatial separation in different compartments
(C) Complete degradation of all degradative enzymes
(D) Lack of specific transporters for products

2005

113. The export of photoassimilates via the inner chloroplast envelope relies on the TPT. If cytosolic Pi drops to critically low levels, what happens to carbon assimilation?
(A) It increases rapidly due to lack of inhibition
(B) It stalls as triose phosphates cannot exit
(C) It switches entirely to photorespiration
(D) It induces immediate opening of stomata

2021

114. The allosteric regulation of Sucrose-Phosphate Synthase (SPS) in the cytosol includes:
(A) Activation by glucose-6-phosphate and inhibition by inorganic phosphate (Pi)
(B) Activation by Pi and inhibition by glucose-6-phosphate
(C) Activation by malate and inhibition by citrate
(D) Activation by ATP and inhibition by ADP

2004

115. Match the following plastidial starch biosynthesis enzymes with their specific action.
List I : (Enzymes)
P. Phosphoglucomutase
Q. AGPase
R. Starch Synthase
S. Branching Enzyme
List II : (Actions)
1. Introduces alpha-1,6-glycosidic linkages
2. Elongates the alpha-1,4-glucan chain
3. Converts Glucose-6-P to Glucose-1-P
4. Synthesizes ADP-glucose
(A) P-3, Q-4, R-2, S-1
(B) P-4, Q-3, R-1, S-2
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-2, R-3, S-4

2011

116. Oleosins are crucial structural proteins in seeds whose primary function is to:
(A) Catalyze the breakdown of starch
(B) Coat lipid bodies to prevent coalescence
(C) Act as a storage reserve for nitrogen
(D) Transport lipids across the plasma membrane

2019

117. Photosynthetically Active Radiation (PAR) is quantified physiologically using which unit?
(A) Micromoles of photons per square meter per second
(B) Watts per square meter
(C) Lumens per square foot
(D) Joules per mole

2005

118. Which statement best describes the biochemical anatomy of the thylakoid membrane?

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2014

140. Which sub-compartment of the chloroplast exhibits the most acidic pH during active steady-state photosynthesis?
(A) The stroma
(B) The intermembrane space
(C) The thylakoid lumen
(D) The lipid droplets (plastoglobuli)

2013

141. Identify the INCORRECT statement concerning carotenoids in higher plants.
(A) They are synthesized in the plastid via the MEP pathway
(B) They serve only to expand the action spectrum
(C) They are essential for photoprotection
(D) They consist of long polyene chains

2025

142. The structural integrity of the Light-Harvesting Complex II (LHCII) heavily relies on the binding of specific pigments. A typical LHCII monomer binds:
(A) Chlorophyll a, b, and xanthophylls
(B) Only chlorophyll a
(C) Only beta-carotene
(D) Phycocyanobilin

2010

143. In the context of Photosystem II, what is the role of the primary electron acceptor, pheophytin?
(A) It stabilizes the manganese cluster
(B) It receives an excited electron directly from P680 before transferring it to tightly bound quinones
(C) It transports protons across the membrane
(D) It oxidizes water directly

2013

144. Which molecule serves as the terminal electron acceptor in the linear non-cyclic electron transport chain?
(A) Oxygen
(B) $NADP^+$
(C) Water
(D) Cytochrome f

2017

145. The functional role of the Rieske iron-sulfur protein in the chloroplast is located within the:
(A) Cytochrome b6f complex
(B) Photosystem II core
(C) ATP synthase stator
(D) Light-Harvesting Complex I

2025

146. Which metabolic scenario most strongly upregulates cyclic electron transport?
(A) High ATP demand and low $NADP^+$
(B) High NADPH demand and low ATP demand
(C) Total darkness
(D) Severe magnesium deficiency

NODIA

2021

147. Chemiosmotic coupling strictly requires that the thylakoid membrane is:
(A) Impermeable to protons to maintain the gradient
(B) Highly permeable to all cations
(C) Lacking any lipid content
(D) Unfolded and exposed to the cytosol

2009

148. Light-induced ion fluxes include the movement of chloride ions (Cl^-). What is the primary role of Cl- influx into the lumen?
(A) It maintains electroneutrality during pumping
(B) It acts directly as an electron donor to PSI
(C) It directly inhibits the oxygen-evolving complex
(D) It binds to and inhibits ATP synthase

2011

149. How many turns of the Calvin-Benson cycle are required to yield a net gain of one six-carbon sugar (e.g., glucose equivalent)?
(A) 1
(B) 3
(C) 6
(D) 12

2024

150. Which structural aspect of Rubisco defines the Form I enzyme found in higher plants?
(A) It is composed of 8 large subunits (L8) and 8 small subunits (S8)
(B) It is a simple monomer
(C) It consists only of 2 large subunits (L2)
(D) It lacks any tertiary structure

2010

151. Which of the following Calvin cycle enzymes does NOT require thioredoxin-mediated light activation?
(A) Fructose-1,6-bisphosphatase
(B) Phosphoribulokinase
(C) Rubisco
(D) Sedoheptulose-1,7-bisphosphatase

2004

129. The activation of sedoheptulose-1,7-bisphosphatase in the light is mediated by the reduction of internal disulfide bonds. This reduction is carried out physically by:
(A) Glutathione
(B) Ascorbic acid
(C) Thioredoxin
(D) NADH

2014

130. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : C4 plants require a specialized Kranz anatomy for efficient C4 photosynthesis.
Reason (R) : Spatial separation prevents Rubisco from interacting with atmospheric oxygen.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2002

131. In CAM plants, the initial fixation of CO_2 at night requires a supply of phosphoenolpyruvate (PEP). What is the primary source of this PEP?
(A) Breakdown of storage carbohydrates via glycolysis
(B) Imported directly from the soil
(C) Synthesized from malate via NADP-malic enzyme
(D) Supplied by the photorespiratory pathway

2009

132. During the Calvin cycle, how many molecules of CO_2 must be fixed to produce a net gain of one molecule of dihydroxyacetone phosphate (DHAP)?
(A) 1
(B) 3
(C) 6
(D) 12

2010

133. C4 plants possess a physiological advantage over C3 plants in arid climates primarily because C4 plants:
(A) Conserve water without limiting CO_2 fixation
(B) Do not require water for electron transport
(C) Fix carbon exclusively at night
(D) Lack photorespiration enzymes entirely

2013

134. Which translocator is responsible for the export of newly synthesized triose phosphates from the chloroplast stroma into the cytosol?
(A) Dicarboxylate translocator
(B) Triose phosphate/phosphate translocator (TPT)
(C) ATP/ADP translocator
(D) Malate/a-ketoglutarate translocator

2024

135. The movement of 2-oxoglutarate and glutamate across the chloroplast inner envelope is crucial for which metabolic pathway integrated with carbon assimilation?
(A) Lipid biosynthesis
(B) Photorespiratory ammonia reassimilation
(C) Transient starch synthesis
(D) Sucrose transport

2017

136. The major end-product of photosynthetic carbon assimilation exported to sink tissues in most plants is:
(A) Fructose
(B) Glucose
(C) Sucrose
(D) Maltose

2008

137. Which enzyme is responsible for the cleavage of the branch points (alpha-1,6 linkages) during the degradation of transient starch?
(A) Isoamylase (Debranching enzyme)
(B) Alpha-amylase
(C) Beta-amylase
(D) Starch phosphorylase

2024

138. In cereal grains (e.g., wheat, maize), the major class of storage proteins deposited in the endosperm are:
(A) Albumins
(B) Globulins
(C) Prolamins
(D) Metallothioneins

2016

139. How do plants effectively utilize light wavelengths outside the principal absorption peaks of chlorophyll a?
(A) Through the use of accessory pigments
(B) By generating heat for enzymatic reactions
(C) By bypassing the photosystems
(D) By utilizing specific infrared receptors

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acidic

2011

79. The light-induced efflux of Mg^{2+} from the thylakoid lumen to the stroma plays an essential secondary role in:
(A) Activating key Calvin cycle enzymes such as Rubisco
(B) Deactivating the Oxygen-Evolving Complex activity
(C) Increasing the degradation rate of chlorophyll
(D) Uncoupling ATP synthase from the membrane

2010

80. Identify the INCORRECT statement regarding the Calvin-Benson cycle.
(A) It takes place exclusively in the stroma of the chloroplast
(B) Ribulose-1,5-bisphosphate acts as the primary carbon dioxide acceptor
(C) The reduction phase yields glucose-6-phosphate directly
(D) One molecule of G3P exits the cycle for every 3 CO_2 fixed

2017

81. In the context of Rubisco functionality, carbamylation refers to:
(A) The attachment of a carbohydrate to the enzyme surface
(B) The destruction of the enzyme by reactive oxygen species
(C) The phosphorylation of the enzyme by ATP molecules
(D) Non-catalytic addition of CO_2 to a specific lysine residue

2016

82. Which of the following explains why Rubisco activase is required in vivo?
(A) Rubisco active sites are blocked by sugar phosphates
(B) Rubisco spontaneously produces toxic oxygen species
(C) Rubisco lacks a magnesium-binding site inherently
(D) Rubisco activase directly transports CO_2 into the site

2013

83. The ferredoxin-thioredoxin system links the light reactions to carbon assimilation. Which molecule is the immediate electron donor to thioredoxin in this system?
(A) Ferredoxin-thioredoxin reductase (FTR)
(B) Ferredoxin
(C) NADPH
(D) Cytochrome f

2007

84. Which defining feature of Kranz anatomy contributes most to the high efficiency of C4 photosynthesis?
(A) The massive presence of spongy mesophyll
(B) A specialized bundle sheath layer surrounding vascular tissue
(C) The complete absence of stomata on the lower epidermis
(D) The exceptionally thick cuticle on the upper leaf surface

2007

85. Match the C4 photosynthesis subtype with its characteristic primary decarboxylating enzyme.
List I : (C4 Subtypes)
P. NADP-ME type
Q. NAD-ME type
R. PCK type
S. CAM type (functional analogue)
List II : (Enzymes)
1. NAD-malic enzyme
2. Phosphoenolpyruvate carboxykinase
3. NADP-malic enzyme
4. Both NAD/NADP malic enzyme & PEPCK functionally separated by time
(A) P-3, Q-1, R-2, S-4
(B) P-1, Q-2, R-3, S-4
(C) P-2, Q-3, R-4, S-1
(D) P-4, Q-3, R-1, S-2

2025

86. Which primary structural modification allows CAM plants to separate carboxylation and decarboxylation temporally rather than spatially?
(A) An enlarged vacuole for nocturnal malic acid storage
(B) The complete absence of bundle sheath cells
(C) Two types of chloroplasts in a single cell
(D) The loss of all mitochondrial function

NODIA

2019

87. What is the primary role of the PsbO protein in the Photosystem II complex?
(A) It binds light-harvesting pigments
(B) It stabilizes the manganese cluster of the oxygen-evolving complex
(C) It catalyzes the formation of ATP
(D) It transfers electrons to PSI

2012

152. In NAD-ME type C4 plants, the primary transport metabolite moving from the mesophyll to the bundle sheath is:
(A) Aspartate
(B) Malate
(C) Phosphoenolpyruvate
(D) Pyruvate

2003

153. What is the fundamental requirement for the generation of a proton motive force across the thylakoid membrane?
(A) High conservation but restricted growth
(B) High growth but high water loss
(C) Frost resistance but heat sensitivity
(D) Nitrogen fixation but carbon loss

2007

154. During photorespiration, which transport mechanism is responsible for moving glycolate from the chloroplast to the peroxisome?
(A) A specific glycolate/glycerate translocator in the inner envelope
(B) Passive diffusion through porins
(C) Vesicular trafficking via the Golgi
(D) The malate-oxaloacetate shuttle

2002

155. Which photosynthetic pathway inherently exhibits the lowest carbon isotope discrimination (i.e., less negative $\delta^{13}C$ values)?
(A) C4 pathway
(B) C3 pathway
(C) Photorespiratory pathway
(D) Glycolytic pathway

2017

156. What is the primary sugar exported from the chloroplast to the cytosol during the degradation of transient starch at night?
(A) Maltose
(B) Glucose
(C) Sucrose
(D) Fructose

2011

157. Which specific malate-dependent shuttle operates across the inner chloroplast envelope to export reducing equivalents generated in the light?
(A) The malate-oxaloacetate shuttle
(B) The malate-aspartate shuttle
(C) The malate-citrate shuttle
(D) The malate-pyruvate shuttle

2011

158. The commitment step of cytosolic sucrose biosynthesis is catalyzed by Sucrose-Phosphate Synthase (SPS). The products of this reaction are:
(A) Sucrose-6-phosphate and free UDP
(B) Sucrose and free UDP
(C) Fructose and UDP-glucose
(D) Glucose and Sucrose

2018

159. Starch exists within plastids as semi-crystalline granules consisting of two polymers. Which statement correctly identifies them?
(A) Amylose (linear) and Amylopectin (highly branched)
(B) Amylose (highly branched) and Amylopectin (linear)
(C) Cellulose (linear) and Glycogen (highly branched)
(D) Callose (linear) and Inulin (branched)

2024

160. Seed storage lipids are typically composed of triacylglycerols (TAGs). What is the direct biochemical precursor to the glycerol backbone of TAGs?
(A) Glycerol-3-phosphate
(B) Glyceraldehyde-3-phosphate
(C) Phosphoenolpyruvate
(D) Pyruvate

2003

161. The specific wavelength characteristic of the red drop effect in photosynthesis demonstrates a sharp decline in quantum yield beyond:
(A) 680 nm
(B) 400 nm
(C) 500 nm
(D) 800 nm

2005

162. How does the structure of the thylakoid network ensure an optimal balance of energy distribution between photosystems?
(A) By separating PSII grana from PSI stroma
(B) By completely isolating PSII in the stroma
(C) By strictly mixing PSII and PSI everywhere
(D) By linking them with rigid structural proteins

2019

163. The biosynthesis of phycobilins in cyanobacteria diverges from chlorophyll synthesis after the formation of which intermediate?
(A) Heme

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2004

186. The phenomenon where an excited pigment molecule returns to its ground state by emitting a photon of longer wavelength is termed:
(A) Fluorescence
(B) Resonance energy transfer
(C) Phosphorescence
(D) Internal conversion

2004

187. The unique redox-active tyrosine residue, Tyr-Z, in Photosystem II is located on which specific subunit?
(A) D1 protein
(B) D2 protein
(C) CP43
(D) PsbO (manganese stabilizing protein)

2017

188. Which iron-sulfur center serves as the terminal electron acceptor within the Photosystem I core complex before electron transfer to ferredoxin?
(A) Fa/Fb
(B) Fx
(C) Rieske center
(D) Cytochrome f

2012

189. During linear electron transport, how many protons are theoretically translocated from the stroma to the lumen per pair of electrons transferred?
(A) 2
(B) 4
(C) 6
(D) 8

2001

190. In pseudocyclic electron transport (Mehler reaction), what limits the continued generation of ATP?
(A) Antioxidant capacity and O_2 availability
(B) Depletion of $NADP^+$
(C) The structural breakdown of PSI
(D) The accumulation of malate

2011

191. The binding change mechanism for ATP synthesis, proposed by Paul Boyer, outlines three distinct conformational states for the catalytic beta subunits. What are they?
(A) Open, Loose, and Tight states
(B) Open, Closed, and Blocked states
(C) Alpha, Beta, and Gamma states
(D) Forward, Reverse, and Neutral states

NODIA

2009

192. Which conformational change occurs structurally in the thylakoid membrane when light induces an influx of protons into the lumen and a rise in Mg2+ in the stroma?
(A) Tightening of grana appression
(B) Unstacking of grana membranes
(C) Dissociation of ATP synthase
(D) Rupture of chloroplast envelope

2006

193. How many molecules of ATP and NADPH are respectively required to regenerate 3 molecules of RuBP from 5 molecules of G3P in the Calvin cycle?
(A) 3 ATP and 0 NADPH
(B) 3 ATP and 2 NADPH
(C) 1 ATP and 1 NADPH
(D) 0 ATP and 0 NADPH

2005

194. The specific activity of Rubisco is often measured in vitro. What essential cofactor must be added to the assay medium to ensure the enzyme is fully carbamylated?
(A) Magnesium ion (Mg^{2+})
(B) Copper ion (Cu^{2+})
(C) Ferrous ion (Fe^{2+})
(D) Zinc ion (Zn^{2+})

2004

195. Which enzyme class reverses the light-dependent activation of Calvin cycle enzymes when plants are placed in the dark?
(A) Endogenous oxidized redox systems
(B) Protein kinases class enzymes
(C) Thioredoxin reductases complexes
(D) Ubiquitin ligases class enzymes

2023

196. Kranz anatomy features an intricate concentric arrangement. Which tissue layer immediately surrounds the vascular bundle in a typical C4 leaf?
(A) Bundle sheath
(B) Epidermis
(C) Spongy mesophyll
(D) Palisade mesophyll

2011

197. Which of the following is a primary biochemical limitation of the CAM pathway?
(A) Restricted vacuolar malic capacity
(B) Requirement of continuous light
(C) PEP carboxylase heat degradation
(D) Inability to synthesize starch

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2004

174. In C4 plants, the enzyme pyruvate, phosphate dikinase (PPDK) functions in the mesophyll chloroplast to regenerate PEP. This reaction uniquely consumes:
(A) ATP, yielding AMP and PPi
(B) ATP, yielding ADP and Pi
(C) GTP, yielding GDP and Pi
(D) UTP, yielding UDP and Pi

2003

175. During which phase of Crassulacean Acid Metabolism (CAM) does the maximum net fixation of atmospheric CO_2 occur?
(A) Phase I (Night)
(B) Phase II (Early morning)
(C) Phase III (Midday)
(D) Phase IV (Late afternoon)

2002

176. Which molecule acts as the nitrogen donor for the conversion of glyoxylate to glycine in the photorespiratory peroxisome?
(A) Glutamate or Serine
(B) Asparagine
(C) Nitrate
(D) Ammonia directly

2006

177. The "CO_2 compensation point" is defined as the atmospheric CO_2 concentration at which:
(A) Uptake rate exactly equals release rate
(B) The rate of photosynthesis equals zero
(C) Plants switch from C3 to C4 metabolism
(D) Stomata forcibly close during stress

2015

178. What would occur if the triose phosphate/ phosphate translocator (TPT) were defective in a mature leaf?
(A) Cytosolic sucrose synthesis impairment
(B) Starch synthesis in chloroplast cease
(C) Export of glucose-1-phosphate increase
(D) Photorespiration metabolic flow stop

2004

179. The dicarboxylate translocator of the chloroplast inner envelope specifically transports which of the following pairs?
(A) Malate and alpha-ketoglutarate
(B) Sucrose and fructose
(C) Triose phosphate and 3-phosphoglycerate
(D) ATP and ADP

NODIA

2017

180. Which cytosolic enzyme cleaves sucrose into fructose and UDP-glucose and plays a major role in sink tissues?
(A) Sucrose synthase
(B) Invertase
(C) Sucrose-phosphate synthase
(D) Hexokinase

2005

181. In the regulation of plastidial starch biosynthesis, the enzyme AGPase is allosterically inhibited by:
(A) Inorganic phosphate (Pi)
(B) 3-Phosphoglycerate (3-PGA)
(C) Fructose-1,6-bisphosphate
(D) Sucrose

2003

182. Developing seeds sink massive amounts of photoassimilate to construct carbon reserves. The synthesis of the major storage carbohydrates (starch) within the amyloplasts requires the import of:
(A) Hexose phosphates or ADP-glucose
(B) Sucrose directly from the cytosol
(C) Pyruvate from the mitochondrion
(D) Fructose from the vacuolar sap

2002

183. Absorption spectra characterize the wavelength of light absorbed by a pigment. Which wavelength region corresponds to the "Soret band" characteristic of chlorophylls?
(A) Blue region (approx 430 nm)
(B) Red region (approx 660 nm)
(C) Green region (approx 550 nm)
(D) Far-red region (approx 730 nm)

2007

184. The highly folded nature of thylakoid membranes in grana primarily serves to:
(A) Maximize antenna complex density
(B) Decrease surface area to volume
(C) Isolate DNA from the rest of cell
(D) Prevent the diffusion of oxygen gas

2022

185. Which enzyme is responsible for the light-dependent reduction of protochlorophyllide to chlorophyllide during chlorophyll biosynthesis in angiosperms?
(A) Protochlorophyllide oxidoreductase
(B) GSA aminotransferase enzyme
(C) Magnesium-chelatase complex
(D) Chlorophyll synthase enzyme

2022

210. Which statement INCORRECTLY identifies a functional property of Photosystem I?
(A) Its reaction center is a P700 chlorophyll pair
(B) It can operate independently in cyclic electron flow
(C) It requires manganese to function
(D) Its primary electron acceptor is a chlorophyll monomer, A0

2012

211. In the Z-scheme, the midpoint redox potential of P680 is extremely negative. What is its approximate value?
(A) -1.2 V
(B) -0.6 V
(C) +0.8 V
(D) +1.2 V

2015

212. Which inhibitor specifically blocks the electron transfer between Qa and Qb in Photosystem II?
(A) DCMU (Diuron)
(B) Paraquat
(C) Antimycin A
(D) Cyanide

2006

213. The structural stoichiometry of the chloroplast CF0-CF1 ATP synthase includes a c-ring in the CF0 base. In plant chloroplasts, this ring typically consists of how many identical c-subunits?
(A) 8
(B) 10
(C) 14
(D) 20

2011

214. The transition from State 2 back to State 1 allows a rebalancing of excitation energy by:
(A) Dephosphorylating LHCII for grana migration
(B) Activating a protease that degrades LHCII
(C) Phosphorylating PSI to decrease absorption
(D) Moving the PSII core into stroma lamellae

2015

215. Which specific reaction in the Calvin cycle represents the critical reduction step utilizing NADPH?
(A) 1,3-BPG to glyceraldehyde-3-phosphate
(B) ribulose-5-P to ribulose-1,5-BP
(C) 3-PGA to 1,3-bisphosphoglycerate
(D) Cleavage of the 6-carbon intermediate

2002

216. The enzyme Rubisco consists of 8 large (L) and 8 small (S) subunits. The genes encoding these subunits are located:
(A) L subunit in the chloroplast genome, S subunit in the nuclear genome
(B) Both in the nuclear genome
(C) Both in the chloroplast genome
(D) L subunit in the nuclear genome, S subunit in the chloroplast genome

2004

217. Light-dependent alkalization of the stroma is crucial for Calvin cycle activity because:
(A) Rubisco and FBPase have pH 8.0 optima
(B) It causes spontaneous starch degradation
(C) It prevents CO_2 binding to Rubisco
(D) Acidic conditions are required for ATP

2019

218. NAD-ME type C4 plants differ morphologically from NADP-ME types primarily by having bundle sheath chloroplasts with:
(A) Well-developed grana stacks
(B) No thylakoids
(C) Agonal arrangements only
(D) Massive starch grains exclusively

2005

219. During a severe drought, a facultative CAM plant will typically:
(A) Induce CAM, opening stomata at night
(B) Switch completely to C3 photosynthesis
(C) Shed all its leaves immediately
(D) Increase transpiration rates drastically

2007

220. The primary role of catalase in the photorespiratory cycle is to:
(A) Detoxify hydrogen peroxide (H_2O_2) produced in the peroxisome
(B) Oxidize glycolate
(C) Convert serine to hydroxypyruvate
(D) Synthesize ATP

2025

221. Which parameter dictates the theoretical maximum quantum yield of C3 photosynthesis in an oxygen-free environment?
(A) The absolute lack of photorespiration
(B) Temperature alone
(C) The size of the vacuole
(D) The concentration of cytosolic sucrose

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2006

198. The photorespiratory pathway is technically considered a scavenger pathway. What specific carbon compound is actively "scavenged" and returned to the Calvin cycle?
(A) Glycerate (as 3-phosphoglycerate)
(B) Glycolate
(C) Oxaloacetate
(D) Ribulose-1,5-bisphosphate

2008

199. C4 photosynthesis requires a constant spatial compartmentalization. What prevents the back-diffusion of concentrated CO_2 from the bundle sheath cells into the mesophyll?
(A) Suberized layer in sheath walls
(B) Complete lack of plasmodesmata
(C) An active CO_2 export pump
(D) Distance between the cell types

2021

200. Which pathway provides the necessary carbon skeletons for nitrogen assimilation in the chloroplast stroma?
(A) Oxidative pentose phosphate pathway
(B) Photorespiratory glycolate cycle
(C) Beta-oxidation of lipids
(D) Lignin biosynthesis pathway

2014

201. Which intracellular process depends on the chloroplast malate-oxaloacetate shuttle to supply reducing equivalents to the cytosol?
(A) Nitrate reduction
(B) Starch degradation
(C) DNA replication
(D) Protein folding

2009

202. The cytosolic enzyme Fructose-1,6-bisphosphatase (FBPase) is crucial for sucrose synthesis. Its activity is potently inhibited by which regulatory metabolite?
(A) Fructose-2,6-bisphosphate (F2,6BP)
(B) Glucose-6-phosphate
(C) Inorganic phosphate
(D) Triose phosphate

2007

203. The synthesis of amylopectin in the chloroplast requires Starch Synthase and which other critical enzyme to create branch points?
(A) Starch Branching Enzyme (SBE)
(B) Isoamylase
(C) Alpha-amylase
(D) Maltase

2017

204. During seed development, storage proteins are directed into the Protein Storage Vacuole (PSV) via which cellular sorting pathway?
(A) The secretory pathway (ER → Golgi → PSV)
(B) Direct transport from the cytosol via channel proteins
(C) Import through the chloroplast envelope
(D) Pinocytosis from the apoplast

2016

205. The distinct "green" color of leaves primarily arises because chlorophyll:
(A) Reflects or transmits green light
(B) Emits green light fluorescence
(C) Absorbs green light exclusively
(D) Is bound to green proteins

2006

206. Chloroplasts are semi-autonomous organelles. Which feature supports their endosymbiotic origin?
(A) Circular DNA and 70S ribosomes
(B) Linear eukaryotic chromosomes
(C) Lack of a double membrane
(D) Division is nucleus dependent

NODIA

2024

207. Which precursor marks the crucial divergence point separating the porphyrin pathway into the iron (heme) branch and the magnesium (chlorophyll) branch?
(A) Protoporphyrin IX
(B) Uroporphyrinogen III
(C) Coproporphyrinogen III
(D) Delta-aminolevulinic acid (ALA)

2008

208. The xanthophyll cycle provides vital photoprotection. Which xanthophyll accumulates under high light stress to dissipate excess energy?
(A) Zeaxanthin
(B) Violaxanthin
(C) Antheraxanthin
(D) Lutein

2013

209. In the Kok cycle of the Oxygen-Evolving Complex, which step represents the light-independent, rate-limiting oxidation of water releasing O2?
(A) S3 → S4 → S0
(B) S0 → S1
(C) S1 → S2
(D) S2 → S3

(C) Cytochrome b559
(D) Cytochrome c oxidase

2024

234. In cyanobacteria and certain algae, what soluble electron carrier can functionally replace plastocyanin under copper-deficient conditions?
(A) Cytochrome c6
(B) Ferredoxin
(C) Flavodoxin
(D) Rubredoxin

2003

235. What is the fundamental requirement for the generation of a proton motive force across the thylakoid membrane?
(A) The membrane must be selectively impermeable to protons
(B) Oxygen must be continually reduced
(C) The chloroplast must be intact
(D) The stroma must maintain an acidic pH

2012

236. Light-driven state transitions involve a specific kinase (STN7). What signal directly activates this kinase?
(A) The reduction state of the plastoquinone pool/cytochrome b6f complex
(B) The binding of ATP to Rubisco
(C) The synthesis of starch
(D) The opening of stomata

2022

237. In the Calvin cycle, aldolase catalyzes the formation of which intermediate?
(A) Fructose-1,6-bisphosphate
(B) Ribulose-1,5-bisphosphate
(C) 3-Phosphoglycerate
(D) Xylulose-5-phosphate

2015

238. Rubisco activase utilizes energy to alter the conformation of an inactive Rubisco complex. What is the source of this energy?
(A) ATP hydrolysis
(B) GTP hydrolysis
(C) Light absorption directly
(D) Dissipation of the proton gradient

2017

239. Which enzyme is a classical target of the ferredoxin-thioredoxin regulatory system and is responsible for producing fructose-6-phosphate?
(A) Fructose-1,6-bisphosphatase (FBPase)
(B) Phosphofructokinase
(C) Fructose bisphosphate aldolase
(D) Hexokinase

2017

240. In the C4 pathway (NADP-ME subtype), which specific metabolite returns from the bundle sheath to the mesophyll to regenerate PEP?
(A) Pyruvate
(B) Alanine
(C) Aspartate
(D) Malate

2016

241. What physiological condition overwhelmingly favors the expression of CAM photosynthesis in facultative CAM species?
(A) Water stress or salinity
(B) Heavy rainfall
(C) Excessive shading
(D) Extreme cold

2006

242. Which plastid type is primarily responsible for the synthesis and storage of carotenoid pigments in flower petals and ripening fruits?
(A) Chromoplasts
(B) Amyloplasts
(C) Etioplasts
(D) Leucoplasts

2021

243. The energetic efficiency of C4 photosynthesis is relatively independent of temperature, whereas C3 efficiency declines sharply at high temperatures. Why?
(A) C3 photorespiration rises with temperature
(B) C4 plants lack Rubisco entirely
(C) C4 plants close stomata when hot
(D) ATP synthase operates faster in C4

2019

244. If cytosolic orthophosphate (Pi) is sequestered (e.g., by feeding leaves mannose), photosynthesis rapidly declines. This represents a classic limitation known as:
(A) Triose phosphate utilization (TPU) limitation
(B) Rubisco limitation
(C) Electron transport limitation
(D) Stomatal limitation

2024

245. Which metabolite physically crosses the chloroplast envelope via the dicarboxylate translocator to support the transport of reducing power in the malate-oxaloacetate shuttle?
(A) Malate

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2018

222. The triose phosphate/phosphate translocator (TPT) transports specific molecules. Which of the following is NOT transported by TPT?
(A) Fructose-6-phosphate (F6P)
(B) Dihydroxyacetone phosphate (DHAP)
(C) Glyceraldehyde-3-phosphate (G3P)
(D) 3-Phosphoglycerate (3-PGA)

2014

223. What role does the dicarboxylate translocator play in the assimilation of nitrogen?
(A) Imports 2-oxoglutarate for glutamate synthesis
(B) It directly imports nitrate into chloroplast
(C) It fixes nitrogen gas from the atmosphere
(D) It exports ammonia to the central vacuole

2007

224. The conversion of sucrose to starch in sink tissues (like seeds) strictly requires which intermediate transported into the amyloplast?
(A) Hexose phosphates (e.g., G6P) or ADP-glucose
(B) Malate
(C) Pyruvate
(D) Ribulose-1,5-bisphosphate

2013

225. Which enzyme is responsible for the final committed step of amylose biosynthesis?
(A) Granule-Bound Starch Synthase (GBSS)
(B) Soluble Starch Synthase
(C) Starch Phosphorylase
(D) Disproportionating enzyme

2010

226. Lipids synthesized in developing seeds are stored in oleosomes (lipid bodies). The boundary of an oleosome consists of:
(A) A phospholipid monolayer embedded with oleosins
(B) A standard phospholipid bilayer
(C) A solid protein coat without lipids
(D) A rigid cellulosic wall

2022

227. Which characteristic defines an "action spectrum" as opposed to an "absorption spectrum"?
(A) Plot of response magnitude vs wavelength
(B) Physical light absorbance across spectrum
(C) Assessment of heat dissipated by leaf
(D) Measurement of light reflection from leaf

2013

228. The specialized internal architecture of the chloroplast, forming grana stacks, is stabilized largely by:
(A) Cation-mediated electrostatic interactions between adjacent thylakoid surfaces
(B) Covalent cross-links between LHCII complexes
(C) Massive accumulations of starch between membranes
(D) A rigid internal cytoskeleton

2011

229. Which step in chlorophyll biosynthesis is strictly light-dependent in higher plants but can occur in the dark in gymnosperms and algae?
(A) Reduction of protochlorophyllide to chlorophyllide
(B) Formation of delta-aminolevulinic acid
(C) Insertion of magnesium into protoporphyrin IX
(D) Addition of the phytol tail

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2022

230. Phycobilisomes are highly structured, water-soluble light-harvesting antenna complexes. They are found attached to the stromal surface of the thylakoid in:
(A) Cyanobacteria
(B) Green algae
(C) Higher plant mesophyll cells
(D) Brown algae

2011

231. The primary electron donor of Photosystem II, P680, is structurally composed of:
(A) A dimer of chlorophyll a molecules
(B) A trimer of chlorophyll b molecules
(C) A cluster of bacteriochlorophylls
(D) A single, isolated chlorophyll a molecule

2012

232. Within Photosystem I, which specific component mediates electron transfer between the primary electron acceptor A0 and the iron-sulfur centers?
(A) Phylloquinone (A1)
(B) Plastoquinone
(C) Cytochrome b6
(D) Plastocyanin

2006

233. The cytochrome b6f complex contains a unique, high-potential c-type cytochrome essential for the Q-cycle. What is its specific name?
(A) Cytochrome f
(B) Cytochrome c6

(B) Protoporphyrin IX
(C) Biliverdin IXalpha
(D) Protochlorophyllide

2011

164. Non-photochemical quenching (NPQ) primarily dissipates excess excitation energy as:
(A) Heat
(B) Fluorescence
(C) ATP
(D) Reactive oxygen species

2010

165. Match the secondary electron carriers of PSII to their properties.
List I : (Carriers)
P. Qa
Q. Qb
R. Cytochrome b559
S. Pheophytin
List II : (Properties)
1. Tightly bound plastoquinone, one-electron acceptor
2. Loosely bound plastoquinone, two-electron acceptor
3. Primary electron acceptor from P680
4. Protects against photoinhibition, exact role debated

(A) P-1, Q-2, R-4, S-3
(B) P-2, Q-1, R-4, S-3
(C) P-1, Q-3, R-2, S-4
(D) P-3, Q-2, R-1, S-4

2021

166. Which structural component serves as the unique electron donor directly reducing P700+ in Photosystem I?
(A) Plastocyanin
(B) Plastoquinol
(C) Cytochrome f
(D) Water

2025

167. Identify the step where protons are released into the thylakoid lumen during linear electron transport.
(A) Oxidation of water and plastoquinol
(B) Reduction of $NADP^+$ by FNR enzyme
(C) Reduction of plastoquinone by PSII
(D) Transport of electrons through plastocyanin

2014

168. Cyclic electron flow differs physically from linear electron flow because it bypasses which of the following complexes?
(A) Photosystem II
(B) Cytochrome b6f
(C) Photosystem I
(D) ATP synthase

2021

169. What experimental evidence most definitively supports the chemiosmotic theory of ATP synthesis in chloroplasts?
(A) ATP synthesis during acid-base transition
(B) The direct visualization of electron flow
(C) CO_2 requirement for ATP generation
(D) The discovery of Rubisco enzymes

2001

170. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : The chloroplast stroma becomes slightly alkaline during active photosynthesis.
Reason (R) : Light-driven electron transport removes protons from the stroma to form NADPH and pumps protons into the lumen.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2015

171. The carboxylation of RuBP produces an unstable six-carbon intermediate that immediately cleaves into two molecules of:
(A) 3-Phosphoglycerate (3-PGA)
(B) 2-Phosphoglycolate
(C) Glyceraldehyde-3-phosphate (G3P)
(D) Malate

2006

172. The affinity of Rubisco for CO_2 is characterized by a Km value. A lower Km indicates:
(A) A higher affinity for the substrate
(B) A lower affinity for the substrate
(C) The enzyme is completely inactive
(D) The enzyme strictly acts as an oxygenase

2010

173. The ferredoxin-thioredoxin system modulates enzyme activity through redox changes. Which amino acid residues in the target enzymes are reversibly oxidized/reduced?
(A) Cysteine
(B) Lysine
(C) Serine
(D) Histidine

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(B) Glucose
(C) ATP
(D) NADH

2006

246. What is the key regulatory role of Fructose-2,6-bisphosphate in plant mesophyll cells?
(A) Coordination of sucrose and carbon fixation
(B) Substrate for plastidial starch synthesis
(C) Direct activation of Rubisco enzyme
(D) Primary transport molecule in phloem

2014

247. The conversion of Glucose-1-phosphate (G1P) to ADP-glucose for starch synthesis requires ATP. This reaction is accompanied by the release of:
(A) Inorganic Pyrophosphate (PPi)
(B) ADP
(C) AMP
(D) Orthophosphate (Pi)

2019

248. During seed development, massive accumulation of storage lipids relies on the de novo synthesis of fatty acids. Where are these fatty acids synthesized prior to export for TAG assembly?
(A) Plastid
(B) Cytosol
(C) Endoplasmic Reticulum
(D) Mitochondrion

2025

249. Which statement best encapsulates the "Emerson enhancement effect"?
(A) Simultaneous red and far-red synergistic rate
(B) Efficiency during continuous dark cycles
(C) Faster growth in elevated carbon dioxide
(D) Degradation of chlorophyll under light

2005

250. The precise structural composition of a granum typically involves:
(A) A cylindrical stack of flattened thylakoid discs
(B) A single, spherical vesicle
(C) An interwoven mesh of random lipid tubes
(D) A highly folded inner mitochondrial membrane

2013

251. Which distinctive chemical feature of carotenoids allows them to effectively absorb light and quench triplet chlorophyll?
(A) Extensive system of conjugated double bonds
(B) Presence of a bound magnesium ion
(C) Hydrophilic carboxylic acid functional group
(D) Saturated hydrocarbon chain organization

2013

252. The physical transfer of excitation energy from the antenna to the reaction center is overwhelmingly efficient because:
(A) Pigments are held in optimized orientations
(B) Pigments are distributed randomly in membrane
(C) It relies strictly on random thermal motion
(D) ATP facilitates the direct molecular transfer

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2014

253. Which structural modification protects the Oxygen-Evolving Complex (OEC) from releasing harmful intermediates into the stroma?
(A) Lumenal localization in thylakoid membrane
(B) Encasement in thick starch layer shield
(C) Operational activity strictly in darkness
(D) Shielding by dense plastoquinone layers

2005

254. The iron-sulfur clusters Fa and Fb of Photosystem I are bound to which specific protein subunit?
(A) PsaC
(B) PsaA
(C) PsaB
(D) PsaD

2018

255. In the linear electron transport chain, what prevents electrons from flowing backwards from PSI to PSII?
(A) Exergonic irreversible cytochrome steps
(B) A physical barrier composed of starch
(C) The physical rotation of ATP synthase
(D) Light-driven breakdown of ferredoxin

2021

256. Cyclic electron transport relies heavily on a specific pathway redirecting electrons from ferredoxin to the plastoquinone pool. This is often mediated by which membrane complex?
(A) PGR5/PGRL1 or NDH complex pathway
(B) Cytochrome c oxidase complex activity
(C) Rubisco activase regulatory activity
(D) Fructose-1,6-bisphosphatase enzyme activity

2008

257. The stoichiometry of protons translocated to ATP synthesized (H+/ATP ratio) fundamentally depends on:
(A) Subunit count in the rotor ring
(B) Large subunit count in Rubisco

(C) Number of grana stacks present
(D) Overall physical size of leaf

2015

258. Light-induced proton pumping directly creates a pH gradient. Under standard steady-state illumination, the pH of the thylakoid lumen drops to approximately:
(A) 5.5 - 6.5
(B) 2.0 - 3.0
(C) 7.5 - 8.0
(D) 9.0 - 10.0

2001

259. What specific role does the enzyme phosphoribulokinase (PRK) play in the Calvin cycle?
(A) It uses ATP to phosphorylate ribulose-5-phosphate, regenerating RuBP
(B) It fixes CO_2 to RuBP
(C) It reduces 1,3-bisphosphoglycerate
(D) It converts fructose-6-phosphate to glucose-6-phosphate

2007

260. The catalytic promiscuity of Rubisco (acting as both carboxylase and oxygenase) is an unavoidable consequence of:
(A) Identical binding sites for oxygen and carbon dioxide
(B) Absolute lack of specialized active site structure
(C) Dependence on copper ions for enzymatic catalysis
(D) Evolutionary error specific to modern crop plants

2011

261. The ferredoxin-thioredoxin system utilizes the enzyme Ferredoxin-Thioredoxin Reductase (FTR). What unique chemical center allows FTR to perform this reduction?
(A) An iron-sulfur center coupled with redox-active disulfides
(B) A manganese cluster
(C) A copper-zinc center
(D) A heme group

2015

262. A unique structural feature of Kranz anatomy in C4 grass leaves is that bundle sheath chloroplasts often:
(A) Diminished or completely lack grana
(B) Are smaller than mesophyll plastids
(C) Lack the enzyme Rubisco entirely
(D) Form phycobilisome networks

2016

263. In CAM plants, what metabolic signal dictates the shift from nocturnal PEP carboxylation to diurnal decarboxylation?
(A) Clock kinase and light-driven efflux
(B) Exhaustion of vacuolar acid capacity
(C) Complete depletion of internal water
(D) Physical degradation of carboxylase

2006

264. What happens to the two molecules of 2-phosphoglycolate produced by Rubisco oxygenase action during photorespiration?
(A) Yield one 3-PGA and one CO_2 via C_2 cycle
(B) Directly converted to cytosolic sucrose
(C) Excreted from the roots to soil
(D) Polymerized into chloroplast starch

2012

265. Considering water-use efficiency (WUE), order the major photosynthetic pathways from most efficient to least efficient under severe aridity.
(A) CAM > C_4 > C_3
(B) C_4 > CAM > C_3
(C) C_3 > C_4 > CAM
(D) CAM > C_3 > C_4

2006

266. If a mature leaf acts solely as a strong source tissue exporting massive amounts of sucrose, the Triose Phosphate Translocator (TPT) will primarily:
(A) Export triose phosphates for Pi
(B) Import triose from the cytosol
(C) Function completely in reverse
(D) Shut down all metabolic transport

2014

267. The physiological relevance of the malate-oxaloacetate shuttle extends beyond redox transfer. It also critically supports:
(A) Assimilation of newly reduced nitrogen into amino acids
(B) The synthesis of chloroplast DNA
(C) The physical division of the chloroplast
(D) Formation of plasmodesmata

2016

268. Which condition promotes the dephosphorylation (and thus activation) of Sucrose-Phosphate Synthase (SPS) in leaves?
(A) Light and high glucose-6-phosphate
(B) Darkness and high Pi
(C) Severe wilting
(D) Extreme cold shock

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2010

269. A mutant plant lacking the enzyme ADP-glucose pyrophosphorylase (AGPase) would most likely present which specific phenotype?
(A) A total inability to synthesize leaf starch
(B) A massive over-accumulation of leaf starch
(C) Immediate lethality in the dark
(D) Complete loss of chlorophyll

2012

270. Developing seeds exhibit specialized metabolic routing to deposit lipid reserves. The enzyme primarily responsible for the final acylation forming Triacylglycerol (TAG) is:
(A) Diacylglycerol acyltransferase (DGAT)
(B) Acetyl-CoA carboxylase
(C) Lipase
(D) Phosphatidic acid phosphatase

2003

271. According to the quantum requirement of photosynthesis, roughly how many photons are required to fix one molecule of CO_2 in a typical C3 plant?
(A) 2 to 4
(B) 8 to 10
(C) 14 to 16
(D) Over 20

2022

272. The term "appressed regions" of the thylakoid refers to:
(A) The tightly stacked membrane areas within grana
(B) The exposed surfaces of stroma lamellae
(C) The inner boundary of the chloroplast envelope
(D) The space between the inner and outer envelope

2008

273. The phytol chain of a chlorophyll molecule is synthesized via which biochemical pathway?
(A) Methylerythritol phosphate (MEP) pathway
(B) Glycolysis
(C) Shikimic acid pathway
(D) Pentose phosphate pathway

2006

274. Antenna pigment-protein complexes are highly efficient due to minimizing non-radiative energy loss. What is the typical timeframe for excitation transfer to the reaction center?
(A) Picoseconds to nanoseconds
(B) Microseconds to milliseconds
(C) Seconds
(D) Minutes

2003

275. In the structure of Photosystem II, which subunits bind the majority of the internal antenna chlorophylls?
(A) CP43 and CP47
(B) D1 and D2
(C) PsbO and PsbP
(D) LHCII monomers

2008

276. The generation of a strong reductant by PSI is evidenced by the highly negative midpoint potential of its primary electron acceptor, A0. This potential is roughly:
(A) -1.0 V
(B) +0.4 V
(C) 0.0 V
(D) -0.5 V

2015

277. The oxidation of one molecule of plastoquinol (PQH2) at the cytochrome b6f complex is coupled to the translocation of how many protons into the lumen?
(A) 1
(B) 2
(C) 4
(D) 8

2008

278. Pseudocyclic photophosphorylation acts primarily as a protective "safety valve" because it:
(A) Dissipates excess while yielding ATP
(B) Directly stores excess leaf carbon
(C) Yields hydrogen peroxide for growth
(D) Replaces Rubisco with PEP enzyme

2012

279. The isolated CF1 particle of the ATP synthase complex primarily demonstrates which enzymatic activity in vitro if separated from the membrane?
(A) ATPase activity (hydrolysis of ATP)
(B) ATP synthesis activity
(C) Proton pumping
(D) Kinase activity

2022

280. Which component is crucial for stabilizing the State 1/State 2 transition by modulating the architecture of the grana?
(A) LHCII lateral mobility and phosphorylation
(B) Accumulation of starch grains
(C) Diffusion of plastoquinone pool

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between carbon gain and water loss in plants. It is quantitatively defined as the ratio of the amount of carbon dioxide assimilated through photosynthesis to the volume of water lost via transpiration. High efficiency is particularly important for survival and productivity in environments where water availability is a major limiting factor.

18. (D) Inorganic phosphate (Pi)
The triose phosphate/phosphate translocator is a vital transport protein embedded in the inner chloroplast envelope. It facilitates the export of newly synthesized triose phosphates from the stroma to the cytosol, where they are used for sucrose biosynthesis. This transport occurs through a strict one-for-one counter-exchange mechanism, requiring the simultaneous import of one molecule of inorganic phosphate for every triose exported.

19. (C) Reducing equivalents (NADPH/NADH)
The malate-oxaloacetate shuttle provides an essential mechanism for the indirect transfer of reducing equivalents across the impermeable chloroplast envelope. Because $NADP^+$ and NADPH cannot directly cross the membrane, the system utilizes the reversible reduction of oxaloacetate to malate. This process allows the plant to export excess reducing power from the stroma to the cytosol, maintaining the redox balance necessary for various.

20. (A) IV only
Cytosolic sucrose biosynthesis is a highly regulated process where sucrose-phosphate synthase plays a central role in forming sucrose-6-phosphate. Regulatory metabolites like fructose-2,6-bisphosphate ensure that carbon flow is coordinated between synthesis and other pathways. In active mesophyll cells, sucrose synthase is primarily involved in the degradation of sucrose for metabolism rather than its primary synthesis, making it the incorrect enzyme.

21. (D) ADP-glucose pyrophosphorylase (AGPase)
The biosynthesis of starch within plant plastids is primarily regulated at the level of ADP-glucose formation. ADP-glucose pyrophosphorylase catalyzes the rate-limiting step of this pathway, converting glucose-1-phosphate and ATP into the activated precursor ADP-glucose. The activity of this enzyme is sensitive to the metabolic status of the cell, being allosterically activated by 3-phosphoglycerate and inhibited by high levels of inorganic.

22. (A) Oleosomes (lipid bodies)
During the development of seeds, photoassimilates are converted into energy-dense storage lipids, primarily in the form of triacylglycerols. These lipids are synthesized in the endoplasmic reticulum and subsequently accumulated within specialized organelles called oleosomes or lipid bodies. These structures consist of a hydrophobic triacylglycerol core surrounded by a phospholipid monolayer and unique proteins that stabilize the droplets and prevent their.

23. (C) Chlorophylls
The action spectrum of photosynthesis represents the relative effectiveness of different wavelengths of light in driving the photosynthetic process. In higher plants, this spectrum closely correlates with the absorption characteristics of chlorophyll pigments. This close relationship demonstrates that light energy captured by chlorophyll a and chlorophyll b is the primary driver for the excitation of reaction centers and the subsequent chemical.

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24. (A) It facilitates structural curvature necessary for grana stacking
Thylakoid membranes possess a unique lipid composition dominated by monogalactosyldiacylglycerol, a non-bilayer-forming galactolipid. The cone-shaped geometry of these molecules is essential for inducing the high degree of membrane curvature required for the formation of tightly stacked grana. This structural organization optimizes the density of light-harvesting complexes and facilitates efficient energy transfer and electron flow within the complex photosynthetic machinery.

25. (A) I, II, IV and V
Chlorophyll biosynthesis begins with glutamate and proceeds through several regulated steps, including the formation of protoporphyrin IX. This intermediate serves as a common branch point for both heme and chlorophyll production. The insertion of a magnesium ion into the protoporphyrin ring commits the pathway toward chlorophyll synthesis. Additionally, carotenoids are synthesized through the isoprenoid pathway, providing essential accessory pigments.

(C) Beta-amylase
(D) Hexokinase

2023

292. Storage proteins in legume seeds (like soy or pea) are predominantly:
(A) Globulins
(B) Albumins
(C) Prolamins
(D) Glutelins

2004

293. The phenomenon of "chlorophyll fluorescence" is often used as a non-invasive diagnostic tool to measure:
(A) The quantum efficiency of Photosystem II
(B) Root respiration
(C) The rate of starch degradation
(D) The speed of phloem transport

2016

294. The thylakoid membrane relies heavily on specific desaturated lipids to maintain fluidity. The enzyme responsible for introducing these double bonds is called a:
(A) Fatty acid desaturase
(B) Lipase
(C) Acetyl-CoA carboxylase
(D) Phospholipase

2018

295. Which xlass of pigments is entirely water-soluble and stored in the vacuole, hence NOT directly involved in photosynthetic light harvesting?
(A) Anthocyanins
(B) Chlorophylls
(C) Carotenoids
(D) Phycobilins

2002

296. How does the spatial organization of PSII and PSI prevent "spillover" (uncontrolled energy transfer) from PSII to PSI?
(A) Segregation in grana vs stroma regions
(B) Insulation by thick layers of callose
(C) Housing in separate chloroplast types
(D) Operation at different times of the day

2012

297. The structural stability of the Oxygen-Evolving Complex (OEC) strictly requires which essential cation in addition to manganese?
(A) Calcium (Ca^{2+})
(B) Iron (Fe^{2+})
(C) Copper (Cu^{2+})
(D) Zinc (Zn^{2+})

2015

298. Within the PSI core complex, the electron transfer chain sequentially includes A0, A1, FX, FA, and FB. Which statement is true regarding their nature?
(A) A0 is Chl, A1 is quinone, others are clusters
(B) All of them are iron-sulfur clusters
(C) All of them are distinct quinone species
(D) They are all tightly bound copper ions

2005

299. In the cytochrome b6f complex, the high-potential chain transfers an electron to plastocyanin via which structural component?
(A) The Rieske iron-sulfur protein and cytochrome f
(B) Cytochrome b6
(C) Cytochrome b559
(D) Ferredoxin

2005

300. The physiological significance of the water-water cycle (pseudocyclic electron flow) is most pronounced under which environmental condition?
(A) High light intensity and low CO_2 availability
(B) Total darkness and low leaf respiration
(C) Submerged aquatic environments with low O_2
(D) Optimal light, water, and nutrient supply

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(D) Changes in chloroplast volume

2014

281. In the Calvin cycle, which specific reaction requires both ATP and NADPH?
(A) Reduction of 3-phosphoglycerate to glyceraldehyde-3-phosphate
(B) Carboxylation of RuBP
(C) Isomerization of glyceraldehyde-3-phosphate to dihydroxyacetone phosphate
(D) Regeneration of ribulose-1,5-bisphosphate from ribulose-5-phosphate

2006

282. The specific inhibitor of Rubisco that binds tightly to the uncarbamylated enzyme in the dark is:
(A) 2-Carboxyarabinitol-1-phosphate (CA1P)
(B) Fructose-2,6-bisphosphate
(C) Phosphoenolpyruvate
(D) Dithiothreitol (DTT)

2008

283. During light activation of Calvin cycle enzymes, the reduction of target disulfides by thioredoxin results in:
(A) Conformational changes that expose or shape the active site for catalysis
(B) Covalent attachment of thioredoxin to the enzyme
(C) Immediate degradation of the enzyme
(D) Relocation of the enzyme to the cytosol

2001

284. In PCK-type C4 plants, the decarboxylation in the bundle sheath cells uniquely yields which metabolite alongside CO_2?
(A) Phosphoenolpyruvate
(B) Pyruvate
(C) Alanine
(D) Aspartate

2007

285. A key defining biochemical feature of Phase IV of CAM is:
(A) Stomatal opening in the late afternoon allowing direct C3 photosynthesis
(B) Complete stomatal closure and rapid malate synthesis
(C) Massive vacuolar expansion
(D) Decarboxylation of starch

2025

286. What is the fundamental net result of the photorespiratory cycle acting on one molecule of oxygen instead of carbon dioxide?
(A) Consumption of energy and 0.5 CO_2 loss
(B) Gain of one molecule of glucose sugar
(C) Net gain of one ATP molecule reserve
(D) Yield of exactly two 3-PGA molecules

2007

287. Compared to C3 plants, C4 crop plants generally exhibit higher maximum rates of photosynthesis. What is the primary underlying biochemical reason?
(A) C4 pump saturates Rubisco with CO_2
(B) C4 plants have a much faster Rubisco
(C) C4 plants synthesize ATP without light
(D) C4 plants lack photorespiration genome

2004

288. Which of the following is the most immediate consequence of D1 protein damage in Photosystem II under high light stress?
(A) Immediate cessation of electron transport to plastoquinone
(B) Rapid increase in Calvin cycle enzyme activity
(C) Reversal of ATP synthase rotation
(D) Immediate breakdown of chlorophyll b

2001

289. Which enzyme is responsible for the direct conversion of oxaloacetate to malate in the chloroplast during the operation of the malate-oxaloacetate shuttle?
(A) NADP-malate dehydrogenase (NADP-MDH)
(B) Malic enzyme
(C) PEP carboxylase
(D) Citrate synthase

2002

290. The partitioning of carbon between starch (chloroplast) and sucrose (cytosol) is strictly coordinated. High cytosolic Pi levels generally signal:
(A) Abundant sink demand and promote sucrose export while inhibiting starch synthesis
(B) Low sink demand and promote starch synthesis
(C) Severe drought stress
(D) A lack of available light energy

2008

291. Transient starch degradation involves multiple enzymes. Which enzyme is primarily responsible for the phosphorolytic cleavage of the linear glucan chains?
(A) Starch phosphorlyase
(B) Alpha-amylase

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thereby producing ATP without the simultaneous formation of reducing equivalents like NADPH.

9. (B) A proton motive force consisting of a pH gradient and electrical potential
The synthesis of ATP in chloroplasts is fundamentally governed by the chemiosmotic coupling of electron transport to phosphorylation. Light-driven reactions establish a robust proton motive force across the thylakoid membrane, characterized by a significant pH gradient and electrical potential. This stored electrochemical energy is then utilized by the CF0-CF1 ATP synthase complex to catalyze the conversion of ADP into ATP.

10. (A) Both A and R are true and R is the correct explanation of A.
During photosynthesis, the active transport of protons into the thylakoid lumen creates an electrochemical potential. To maintain electrical neutrality and stabilize the resulting charge imbalance, magnesium ions are concurrently moved from the lumen into the stroma. This light-induced efflux of magnesium serves a dual purpose by compensating for the positive charge of protons while simultaneously activating several key stromal enzymes.

11. (D) Ribulose-1,5-bisphosphate carboxylase/ oxygenase
The initiation of the Calvin-Benson cycle depends on the carboxylation of a five-carbon sugar phosphate. Ribulose-1,5-bisphosphate carboxylase/oxygenase catalyzes this essential step, incorporating atmospheric carbon dioxide into a stable organic framework. As the most abundant enzyme on Earth, it regulates the entry of inorganic carbon into the biosphere, serving as a primary control point for global photosynthetic productivity and biomass.

12. (A) One molecule of 3-phosphoglycerate and one molecule of 2-phosphoglycolate
Rubisco exhibits a bifunctional nature by reacting with both carbon dioxide and molecular oxygen. When oxygen serves as the substrate, the enzyme catalyzes an oxygenation reaction that splits the five-carbon ribulose-1,5-bisphosphate. This process directly results in the production of one three-carbon molecule, 3-phosphoglycerate, and one two-carbon molecule, 2-phosphoglycolate, the latter of which must be processed through the complex photorespiratory scavenger pathway.

13. (B) By reducing enzyme disulfide bonds to sulfhydryl groups in the light
The ferredoxin-thioredoxin system functions as a critical regulatory link between light-driven electron transport and metabolic enzyme activity. Upon illumination, electrons from ferredoxin reduce thioredoxin, which subsequently targets specific disulfide bonds in Calvin cycle enzymes. By converting these disulfide bridges into sulfhydryl groups, the system induces conformational changes that activate the enzymes, ensuring that carbon fixation occurs only when light is available.

14. (B) Kranz anatomy
C4 plants utilize a specialized internal leaf structure known as Kranz anatomy to enhance the efficiency of carbon fixation. This arrangement involves two distinct cell types: mesophyll cells and bundle sheath cells. Initial carboxylation occurs in the mesophyll, while the Calvin cycle is restricted to the bundle sheath cells. This spatial separation concentrates carbon dioxide around Rubisco, effectively minimizing the oxygenase activity.

15. (A) I and II
Crassulacean Acid Metabolism represents an evolutionary adaptation for water conservation in arid environments. CAM plants utilize a temporal separation of carbon fixation, opening their stomata exclusively at night to absorb carbon dioxide. During these nocturnal hours, PEP carboxylase fixes carbon into malate, which is then stored in the large central vacuole. This strategy minimizes transpirational water loss while ensuring sufficient carbon.

16. (A) Chloroplast, peroxisome, mitochondrion
The photorespiratory cycle is a complex metabolic pathway that facilitates the recovery of carbon lost during the oxygenation reaction of Rubisco. This essential process requires the highly coordinated interaction of three distinct subcellular compartments. Reactions initiated in the chloroplast proceed through the peroxisome and then the mitochondrion before returning to the chloroplast. This inter-organellar cooperation ensures the efficient recycling of phosphoglycolate.

17. (B) Water-use efficiency (WUE)
Water-use efficiency serves as a critical physiological index representing the balance

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35. (A) IV, II, III, I
Rubisco activation is a multi-step process required for the enzyme to become catalytically competent. Initially, Rubisco activase must remove inhibitory sugar phosphates from the active site. This allows for the carbamylation of a specific lysine residue by a non-substrate carbon dioxide molecule. Finally, a magnesium ion binds to the carbamate, completing the formation of the active site capable of binding the.

36. (B) Triose phosphate isomerase
Most enzymes in the Calvin cycle are subject to light-dependent regulation via the ferredoxin-thioredoxin system to ensure metabolic coordination. However, triose phosphate isomerase is a notable exception as it is generally considered to be constitutively active. This enzyme facilitates the rapid interconversion between glyceraldehyde-3-phosphate and dihydroxyacetone phosphate, maintaining the equilibrium necessary for subsequent reactions in carbon assimilation and sucrose synthesis.

37. (D) NADP-malic enzyme
In C4 plants of the NADP-malic enzyme subtype, the concentration of carbon dioxide around Rubisco involves a specialized decarboxylation step. Malate, which is transported from mesophyll cells to the bundle sheath, enters the bundle sheath chloroplasts. There, the NADP-malic enzyme catalyzes the decarboxylation of malate, releasing carbon dioxide for the Calvin cycle while simultaneously producing pyruvate and reducing power in the.

38. (A) Minimization of water loss in arid environments
The evolutionary development of Crassulacean Acid Metabolism was primarily driven by the need to minimize water loss in extremely arid or water-limited environments. By closing stomata during the hot daytime and opening them at night, CAM plants significantly reduce transpiration. This adaptation allows these plants to survive and thrive in deserts and epiphytic habitats where maintaining a positive water balance is.

39. (B) Carbon dioxide and ammonia
During the mitochondrial phase of the photorespiratory cycle, two molecules of glycine are converted into one molecule of serine. This reaction is catalyzed by the glycine decarboxylase complex and serine hydroxymethyltransferase. The process involves the release of one molecule of carbon dioxide and one molecule of ammonia, alongside the production of NADH. This step is critical for recovering carbon from the.

40. (A) I only
C4 photosynthesis is an advanced metabolic pathway that effectively concentrates carbon dioxide around Rubisco, virtually eliminating photorespiration and enhancing nitrogen use efficiency. However, this process comes at an energetic cost, as the C4 cycle requires more ATP per molecule of carbon dioxide fixed compared to the C3 pathway. Therefore, statements claiming C4 requires less ATP for carbon fixation are fundamentally incorrect.

41. (A) Orthophosphate (Pi)
The export of triose phosphates from the chloroplast stroma to the cytosol is mediated by the triose phosphate/phosphate translocator. This transport system functions as an antiporter, meaning that for every molecule of triose phosphate exported, one molecule of inorganic phosphate must be imported into the chloroplast. Consequently, the rate of export is heavily dependent on the availability of cytosolic.

42. (D) The malate-oxaloacetate shuttle
The malate-oxaloacetate shuttle is the primary mechanism for balancing the ATP to NADPH ratio between the chloroplast and the cytosol. Since pyridine nucleotides cannot directly traverse the inner envelope, the shuttle uses malate and oxaloacetate as transport vehicles for reducing equivalents. This system allows the chloroplast to export excess reducing power generated by light reactions, supporting essential cytosolic processes.

43. (B) Inhibiting FBPase and activating PPi-PFK
Fructose-2,6-bisphosphate serves as a master regulatory metabolite in the plant cytosol, coordinating carbon partitioning between sucrose synthesis and glycolysis. It exerts its control by potently inhibiting the enzyme cytosolic fructose-1,6-bisphosphatase while simultaneously activating the pyrophosphate-dependent phosphofructokinase. This dual action ensures that the rate of sucrose production is responsive to the metabolic needs and the overall carbon status of the.

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26. (B) Non-photochemical quenching (NPQ) via the xanthophyll cycle
Under conditions of excessive light intensity, plants utilize non-photochemical quenching as a critical photoprotective mechanism. This process safely dissipates excess excitation energy as harmless heat, preventing the formation of damaging reactive oxygen species. The xanthophyll cycle plays a central role in this regulation, involving the rapid conversion of violaxanthin to zeaxanthin, which facilitates the thermal dissipation of energy within antenna.

27. (C) The S-state transitions of the Oxygen-Evolving Complex
The Kok clock model describes the cyclical mechanism of water oxidation within the oxygen-evolving complex of Photosystem II. This process involves a series of five distinct oxidation states, known as S-states, which accumulate the four oxidizing equivalents necessary to split two water molecules. Each absorption of a photon advances the manganese cluster to the next state, eventually resulting in oxygen.

28. (D) It transfers electrons from P700 to the iron-sulfur clusters
Phylloquinone, also identified as vitamin K1, is a specialized redox cofactor located within the reaction center of Photosystem I. It functions as the secondary electron acceptor, labeled A1, in the electron transport chain. Upon excitation of the P700 reaction center, phylloquinone receives electrons from the primary acceptor chlorophyll and subsequently transfers them to the internal iron-sulfur clusters for final.

29. (B) Plastocyanin
Plastocyanin is a small, water-soluble copper protein located within the thylakoid lumen that plays a crucial role in the photosynthetic electron transport chain. It acts as a mobile carrier, shuttling electrons from the cytochrome b6f complex directly to the reaction center of Photosystem I. By reducing the oxidized P700+ pigment, plastocyanin allows the photosystem to remain active for subsequent light.

30. (B) PSII → Plastoquinone → Cytochrome b6f → Plastocyanin → PSI
Linear electron transport in chloroplasts follows a specific pathway known as the Z-scheme. Electrons extracted from water at Photosystem II are first transferred to the plastoquinone pool and then to the cytochrome b6f complex. From there, the mobile carrier plastocyanin delivers the electrons to Photosystem I. This sequential flow ensures the effective conversion of solar energy into chemical power for the.

31. (B) Superoxide radical
The Mehler reaction occurs when electrons from the reducing side of Photosystem I are transferred directly to molecular oxygen instead of NADP+. This process results in the production of the superoxide radical, a highly reactive and potentially damaging byproduct. Plants must utilize robust antioxidant defense systems, such as superoxide dismutase, to detoxify these radicals and protect the photosynthetic apparatus from.

32. (A) The rotation of the gamma subunit driven by proton flux
The synthesis and release of ATP by the CF1 unit of the chloroplast ATP synthase are driven by mechanical rotation. As protons flow through the CF0 portion, the gamma subunit rotates relative to the stationary catalytic beta subunits. This rotation induces specific conformational changes in the active sites, allowing for the binding of substrates and the subsequent release of the.

33. (D) Light-Harvesting Complex II (LHCII)
State transitions represent a short-term adaptive mechanism used by plants to balance excitation energy between the two photosystems. This regulation is primarily achieved through the reversible phosphorylation of the Light-Harvesting Complex II. When the plastoquinone pool becomes overly reduced, a specific kinase phosphorylates LHCII, causing it to dissociate from Photosystem II and migrate to Photosystem I, thereby optimizing the overall efficiency.

34. (A) ATP
During the reduction phase of the Calvin-Benson cycle, the 3-phosphoglycerate formed during carboxylation undergoes chemical transformation to glyceraldehyde-3-phosphate. This two-step process requires significant energy input from the light reactions. First, 3-phosphoglycerate is phosphorylated to 1,3-bisphosphoglycerate using ATP as the phosphate donor. Subsequently, this intermediate is reduced by NADPH, yielding the triose phosphate molecules necessary for sugar synthesis and cycle.

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53. (D) The translocation of additional protons across the thylakoid membrane
The Q-cycle is a specialized mechanism within the cytochrome b6f complex that enhances the efficiency of energy conversion. As electrons pass through the complex, the cycle facilitates the oxidation of plastoquinol and the subsequent reduction of plastoquinone. This specific pathway directly results in the translocation of additional protons from the stroma into the thylakoid lumen, thereby increasing the proton motive.

54. (C) 2.5
In linear electron transport, the stoichiometry of ATP production per pair of electrons transferred is determined by the number of protons translocated and the requirements of the ATP synthase. Assuming that four protons are moved per electron pair and the synthase requires roughly 4.7 protons per ATP, the theoretical yield is approximately 2.5 molecules of ATP for every pair.

55. (A) I and II
The CF0-CF1 ATP synthase is a multi-subunit enzyme complex that utilizes the proton motive force to generate ATP. The CF0 portion is integrated into the thylakoid membrane and acts as a channel for proton translocation. The CF1 portion projects into the stroma and contains the catalytic sites where phosphorylation occurs. Together, they couple the flow of protons to the.

56. (B) LHCII is dephosphorylated by a specific phosphatase
The transition from State 2 back to State 1 occurs when the plastoquinone pool becomes oxidized, signaling that Photosystem I can accept more electrons. This change triggers the inactivation of the STN7 kinase and the activation of a specific phosphatase. The phosphatase removes the phosphate group from the Light-Harvesting Complex II, allowing it to migrate back to the appressed.

57. (A) Three molecules of ribulose-5-phosphate
During the regeneration phase of the Calvin-Benson cycle, the plant must reconstruct the carbon dioxide acceptor molecule. This process involves a complex series of sugar rearrangements where five molecules of three-carbon glyceraldehyde-3-phosphate are utilized. Through the action of various enzymes, these fifteen carbons are converted into three molecules of five-carbon ribulose-5-phosphate, which are subsequently phosphorylated to regenerate ribulose-1,5-bisphosphate for.

58. (D) An enediolate bound to magnesium
The catalytic mechanism of Rubisco is characterized by the formation of a highly reactive enediolate intermediate. This species is stabilized by a magnesium ion within the enzyme's active site. The enediolate then undergoes nucleophilic attack by carbon dioxide, leading to the formation of a six-carbon intermediate. This transient molecule is subsequently cleaved and protonated to produce two molecules of the three-carbon.

59. (B) Sedoheptulose-1,7-bisphosphatase
Sedoheptulose-1,7-bisphosphatase is a key regulatory enzyme in the Calvin cycle that catalyzes the dephosphorylation of its substrate during sugar rearrangements. Its activity is strictly controlled by the ferredoxin-thioredoxin system. In the light, thioredoxin reduces a critical disulfide bond on the enzyme to sulfhydryl groups. This specific covalent modification is absolutely required for the enzyme to adopt its active conformation and.

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60. (C) IV
C4 photosynthesis is classified into three main subtypes based on the primary decarboxylating enzyme used: NADP-malic enzyme, NAD-malic enzyme, and phosphoenolpyruvate carboxykinase. While these subtypes differ in their biochemical pathways and subcellular localizations, they all share the fundamental characteristic of Kranz anatomy. Therefore, any statement claiming that these subtypes lack the specialized Kranz leaf structure is considered to be.

61. (D) Highly acidic
In CAM plants, the nocturnal fixation of carbon dioxide leads to the massive production of malic acid. This acid is actively transported into the large central vacuole for storage until the following day. As a result of this significant accumulation of protons and malate ions, the pH of the vacuolar sap drops considerably, causing the cell to become highly.

62. (A) Glycolate
The photorespiratory cycle involves the movement of metabolic intermediates between

44. (C) 3-Phosphoglycerate (3-PGA)
The biosynthesis of starch in plastids is tightly regulated to match the rate of carbon fixation. ADP-glucose pyrophosphorylase, the key enzyme in this pathway, is allosterically activated by 3-phosphoglycerate, a primary product of the Calvin cycle. Conversely, it is inhibited by inorganic phosphate. This regulatory mechanism ensures that starch synthesis increases when photosynthetic products are abundant and decreases when levels are.

45. (D) P-1, Q-2, R-3, S-4
Plant metabolic pathways are highly compartmentalized to ensure efficiency and control. Triacylglycerol synthesis primarily occurs in the endoplasmic reticulum, while initial C4 carboxylation takes place in the mesophyll cytosol. Glycine decarboxylation is a mitochondrial process, and starch accumulation is restricted to plastids like amyloplasts or chloroplasts. This spatial organization prevents futile cycles and allows for the specialized regulation of each.

46. (A) Protein storage vacuoles (PSVs)
During the maturation of seeds, significant amounts of specialized storage proteins are accumulated to provide a nitrogen source for the germinating embryo. These proteins are synthesized on the rough endoplasmic reticulum and subsequently sequestered within dedicated organelles known as protein storage vacuoles. This compartmentalization protects the proteins from premature degradation and ensures they are readily available during the early.

47. (B) The arrangement of conjugated double bonds and substituent groups
The specific absorption spectrum of a pigment molecule is determined by its unique chemical architecture. The arrangement of conjugated double bonds and the presence of various substituent groups on the core structure define the energy levels of the molecule's electrons. These factors dictate which specific wavelengths of light can be absorbed to excite the pigment, thus establishing its characteristic spectral profile.

48. (C) Stroma lamellae (unstacked thylakoids)
The internal structure of the chloroplast features an interconnected system of thylakoid membranes. Grana are stacks of flattened discs that are physically linked by unstacked regions known as stroma lamellae or stroma thylakoids. This continuous membrane network allows for the diffusion of mobile electron carriers and the efficient distribution of protein complexes throughout the organelle, optimizing the light-dependent reactions of.

49. (A) Cyanobacteria and red algae
Phycobilins are specialized accessory pigments that are characteristic of cyanobacteria and certain algal groups, such as red algae. Unlike chlorophylls, these pigments are water-soluble and organized into large complexes called phycobilisomes attached to the thylakoid surface. They effectively capture light in the green and yellow regions of the spectrum, which are not well absorbed by chlorophyll, expanding the.

50. (D) A is false but R is true.
The chloroplast envelope consists of two distinct membranes with differing properties. While the outer membrane contains porins that allow the relatively free passage of small molecules, the inner membrane is highly selective and serves as a major permeability barrier. It contains a diverse array of specific translocators that strictly regulate the movement of ions and metabolites between the stroma and the.

51. (C) Manganese
The Oxygen-Evolving Complex of Photosystem II is responsible for the critical process of water splitting. Its catalytic center contains a unique inorganic cluster composed of four manganese ions and one calcium ion. Manganese is essential due to its ability to exist in multiple oxidation states, allowing the complex to accumulate the positive charges necessary to extract four electrons from.

52. (A) Rieske iron-sulfur protein
The Rieske iron-sulfur protein is an essential component of the cytochrome b6f complex in chloroplasts. It plays a pivotal role in the Q-cycle by facilitating the bifurcation of electron flow from plastoquinol. By accepting the first electron, the Rieske protein initiates the transfer pathway to cytochrome f, while directing the second electron toward the cytochrome b6 hemes, effectively.

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ANSWERS

1. (B) 400 to 700 nm
Photosynthetically Active Radiation corresponds to the visible light spectrum that plants utilize for driving photosynthesis. This specific range encompasses wavelengths from approximately 400 to 700 nanometers. Within this band, pigments like chlorophylls and carotenoids absorb photons to excite electrons, initiating the primary light reactions essential for plant growth and chemical energy production in ecosystems.

2. (C) Grana are stacked and predominantly contain Photosystem II
Chloroplast thylakoids exhibit distinct lateral heterogeneity within their internal membrane system. Grana consist of highly organized, tightly stacked membrane discs that are significantly enriched in Photosystem II complexes and their associated antenna systems. Conversely, stroma thylakoids are unstacked, single membrane lamellae that primarily house Photosystem I and ATP synthase, facilitating specific stages of photosynthetic electron transport.

3. (B) Chlorophyll a has a C7 methyl group; chlorophyll b has a formyl group
Chlorophyll molecules share a basic porphyrin-like structure but differ significantly in their chemical substituent groups. In chlorophyll a, the third carbon of the second pyrrole ring is attached to a methyl group. In contrast, chlorophyll b possesses a formyl group at this same position. This subtle structural variation shifts their respective absorption peaks within the solar spectrum.

4. (D) Energy is transferred non-radiatively via dipole-dipole interactions
Energy transfer within light-harvesting antenna systems occurs via a non-radiative process known as Förster resonance energy transfer. This mechanism involves the migration of excitation energy between adjacent pigment molecules through induced dipole-dipole interactions. It ensures that captured solar energy is efficiently funneled toward the reaction center without the physical movement of electrons or the expenditure of metabolic energy.

5. (A) P-2, Q-3, R-1, S-4
Photosystem II operates as a multi-subunit complex where each component performs a specialized role. The D1 and D2 proteins form the core reaction center heterodimer, while the oxygen-evolving complex facilitates water oxidation. Pheophytin serves as the primary electron acceptor following excitation, and plastoquinone Qa acts as a tightly bound electron carrier, ensuring the directional flow of high-energy electrons.

6. (C) PSI is predominantly located in the appressed regions of the grana
Photosystem I is characterized by a reaction center containing P700 and specialized iron-sulfur centers that facilitate electron transfer to ferredoxin. Structurally, these complexes are predominantly localized within the non-appressed regions of the thylakoid membranes, such as the stroma lamellae. This spatial separation from Photosystem II prevents uncontrolled energy spillover and optimizes the efficiency of the linear electron transport chain.

7. (A) Transfer of electrons from plastoquinol to plastocyanin
The cytochrome b6f complex acts as a vital intermediary in the photosynthetic electron transport chain, bridging Photosystem II and Photosystem I. Its primary catalytic function involves the oxidation of plastoquinol and the subsequent reduction of the soluble protein plastocyanin. During this redox process, protons are actively translocated into the thylakoid lumen, contributing to the electrochemical gradient used for synthesis.

8. (D) It produces ATP without the concomitant reduction of $NADP^+$
Cyclic photophosphorylation provides a specialized mechanism for plants to adjust the ratio of chemical energy produced during light reactions. By recycling electrons through Photosystem I and the cytochrome b6f complex, the process generates a proton gradient that drives ATP synthesis. Critically, this pathway operates independently of Photosystem II,

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three different organelles. Glycolate is the primary molecule that connects the chloroplast to the peroxisome. It is produced in the chloroplast from the dephosphorylation of 2-phosphoglycolate and then exported to the peroxisome. Once inside, glycolate is oxidized by glycolate oxidase, continuing the pathway for carbon recovery and recycling within the.

63. (C) It loses fixed carbon and consumes energy
From an energetic and productivity perspective, photorespiration is often viewed as a wasteful process in C3 crops. It involves the loss of previously fixed carbon as carbon dioxide and requires the significant consumption of ATP and reducing power (NADPH) to recycle the 2-phosphoglycolate. This reduces the overall efficiency of photosynthesis, particularly under conditions of high temperature or low carbon dioxide.

64. (A) The absolute requirement for imported orthophosphate (Pi)
The triose phosphate/phosphate translocator facilitates the export of photosynthetic products, but its activity is strictly regulated. Because it functions as an obligate antiporter, the export of one triose phosphate molecule is coupled to the import of one inorganic phosphate molecule. Therefore, a low concentration of cytosolic orthophosphate becomes the primary limitation, preventing the further export of triose phosphates.

65. (B) II and V
Intracellular integration relies on specific membrane transporters to maintain metabolic balance. While the dicarboxylate translocator moves malate and alpha-ketoglutarate, the chloroplast inner envelope is actually impermeable to NAD+ and NADH. Furthermore, starch degradation products can and do leave the chloroplast, primarily as maltose or glucose. Thus, statements regarding NADH permeability and the inability of starch products to.

66. (B) Phosphorylation by an SPS-kinase, which generally inactivates the enzyme
Sucrose-phosphate synthase is a key regulatory enzyme that controls the rate of sucrose synthesis in the plant cytosol. Its activity is modulated by reversible covalent modification. Specifically, the enzyme is phosphorylated by a dedicated SPS-kinase during periods of low light or darkness, which results in its inactivation. This mechanism ensures that sucrose production is synchronized with the availability of.

67. (A) ADP-glucose
Transient starch is synthesized in the chloroplast during the day to store excess carbon for use at night. This process utilizes ADP-glucose as the direct glycosyl donor for starch synthase. ADP-glucose is produced from glucose-1-phosphate and ATP by the enzyme ADP-glucose pyrophosphorylase. This pathway ensures that fixed carbon is efficiently converted into a stable storage form within the stroma.

68. (B) Glycolysis and fatty acid biosynthesis
The synthesis of storage lipids in developing seeds requires a significant influx of carbon from sucrose. Once imported, sucrose is broken down into hexoses, which enter the glycolytic pathway to produce acetyl-CoA and reducing power. This carbon flow is then directed into the plastidial fatty acid biosynthesis pathway. The resulting fatty acids are exported to the endoplasmic reticulum for.

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69. (B) Because accessory pigments transfer energy to the reaction center
The action spectrum of photosynthesis does not perfectly match the absorption spectrum of isolated chlorophyll a because plants possess a variety of accessory pigments. Carotenoids and chlorophyll b absorb light at wavelengths where chlorophyll a is less effective. Through resonance energy transfer, these pigments funnel the captured energy to the reaction centers, thereby broadening the range of wavelengths that can.

70. (A) Glutamate → Protoporphyrin IX → Mg-protoporphyrin IX → Protochlorophyllide → Chlorophyll a
Chlorophyll biosynthesis is a highly regulated pathway that starts with glutamate. The process moves through several intermediates, including the key molecule protoporphyrin IX. Following the insertion of magnesium, the pathway continues with the formation of Mg-protoporphyrin IX, followed by protochlorophyllide. Finally, a light-dependent reduction step converts protochlorophyllide into chlorophyllide, which is then esterified with a phytol tail to produce.

temperatures, and limited water availability, where C3 plants would otherwise suffer from.

89. (B) Starch hyper-accumulation and stromal Pi depletion
Chemical inhibition of the triose phosphate/ phosphate translocator prevents the export of photosynthetic products from the chloroplast. As a result, triose phosphates accumulate in the stroma and are diverted toward starch synthesis, leading to starch hyper-accumulation. Concurrently, the lack of phosphate import causes stromal inorganic phosphate levels to drop, eventually stalling the Calvin cycle and overall carbon assimilation processes.

90. (A) Both A and R are true and R is the correct explanation of A.
The malate-oxaloacetate shuttle is an indispensable mechanism for maintaining the redox balance between different plant cell compartments. Because the inner chloroplast envelope lacks a transporter for intact NAD+ or NADH, reducing equivalents cannot directly move across the membrane. By utilizing the reversible interconversion of malate and oxaloacetate, the plant can effectively export reducing power from the stroma to support.

91. (B) A non-reducing sugar that is chemically stable
Sucrose is the primary sugar used for long-distance transport in the phloem of most plant species. Its suitability for this role arises from its chemical nature as a non-reducing disaccharide. Unlike glucose or fructose, sucrose is relatively chemically stable and less reactive with other cellular components. This allows it to be transported at high concentrations without undergoing unwanted chemical.

92. (A) It synthesizes UDP-glucose from glucose-1-phosphate and UTP
In the pathway of cytosolic sucrose biosynthesis, UDP-glucose pyrophosphorylase performs an essential step in activating glucose for subsequent reactions. The enzyme catalyzes the reversible conversion of glucose-1-phosphate and UTP into UDP-glucose and inorganic pyrophosphate. The resulting UDP-glucose then serves as the high-energy glycosyl donor for sucrose-phosphate synthase, which produces the sucrose-6-phosphate precursor needed for final sucrose formation.

93. (B) Neutral sugars for export
Transient starch synthesized during the day serves as a critical carbon reserve for the plant during the night. It is primarily broken down into neutral sugars, such as maltose and glucose, which are then exported from the chloroplast to the cytosol. These sugars provide the carbon skeletons and energy required for cellular respiration, sucrose synthesis, and the continued.

94. (B) Rough endoplasmic reticulum
The accumulation of storage proteins in seeds is a highly coordinated process that depends on the availability of nitrogen. These proteins are primarily translated on the rough endoplasmic reticulum. Following synthesis, they enter the secretory pathway and are transported through the Golgi apparatus before being deposited within specialized protein storage vacuoles, where they remain until required for seed germination and.

95. (A) I only
Chlorophyll b is an essential accessory pigment that significantly broadens the range of light wavelengths a plant can utilize for photosynthesis. It absorbs photons primarily in the blue and yellow-green regions of the spectrum and transfers this energy to chlorophyll a. This allows plants to capture solar energy more effectively, particularly in environments where light availability might be.

96. (A) It contains Calvin cycle enzymes, DNA, and ribosomes
The stroma is the fluid-filled space within the chloroplast that surrounds the thylakoid membranes. It serves as the site for the Calvin-Benson cycle and contains all the necessary enzymes for carbon fixation. Additionally, the stroma houses the chloroplast's own DNA and ribosomes, facilitating the synthesis of some essential organelle proteins. It also maintains a slightly alkaline pH during.

97. (A) Triplet state of chlorophyll and singlet oxygen
Beta-carotene is a vital carotenoid pigment that plays a crucial role in protecting the photosynthetic apparatus from photo-oxidative damage. It functions by directly quenching the triplet state of chlorophyll and singlet oxygen, which are highly reactive and harmful species produced under high light stress. By dissipating

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80. (C) The reduction phase yields glucose-6-phosphate directly
The Calvin-Benson cycle is a three-phase process occurring in the stroma, utilizing ribulose-1,5-bisphosphate as the carbon dioxide acceptor. While the reduction phase utilizes ATP and NADPH to convert 3-phosphoglycerate into triose phosphates, it does not produce glucose-6-phosphate directly. Instead, the primary products are glyceraldehyde-3-phosphate and dihydroxyacetone phosphate, which are then used for subsequent sugar synthesis outside the cycle itself.

81. (D) Non-catalytic addition of CO2 to a specific lysine residue
Carbamylation is an essential non-catalytic modification required for the activation of the Rubisco enzyme. This process involves the spontaneous reaction of a carbon dioxide molecule with a specific lysine residue within the active site to form a carbamate. This modification creates a binding site for a magnesium ion, which is necessary for the enzyme to bind its substrate and catalyze.

82. (A) Rubisco active sites are blocked by sugar phosphates
Rubisco activase is a specialized molecular chaperone required to maintain the catalytic activity of Rubisco in vivo. The active sites of Rubisco often become blocked by the binding of various sugar phosphates, such as its substrate ribulose-1,5-bisphosphate or inhibitory molecules like CA1P. Rubisco activase uses the energy from ATP hydrolysis to remove these inhibitors, ensuring that the active sites.

83. (A) Ferredoxin-thioredoxin reductase (FTR)
In the ferredoxin-thioredoxin system, the transfer of reducing power from the light reactions to metabolic enzymes involves a specific protein cascade. Ferredoxin, reduced by Photosystem I, donates electrons to the enzyme ferredoxin-thioredoxin reductase. This reductase then directly reduces the disulfide bonds of thioredoxin. Once reduced, thioredoxin is capable of activating or deactivating target enzymes in the Calvin cycle by modifying.

84. (B) A specialized bundle sheath layer surrounding vascular tissue
The high efficiency of C4 photosynthesis is largely attributed to Kranz anatomy, characterized by a specialized layer of bundle sheath cells surrounding the vascular tissue. This arrangement allows for the spatial separation of initial carbon fixation and the Calvin cycle. By concentrating carbon dioxide within the bundle sheath, the plant effectively suppresses the oxygenase activity of Rubisco, minimizing wasteful photorespiration.

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85. (A) P-3, Q-1, R-2, S-4
C4 plants are categorized by the primary enzyme used to release carbon dioxide in the bundle sheath cells. The NADP-ME type utilizes the NADP-malic enzyme, while the NAD-ME type relies on the NAD-malic enzyme. The PCK type employs phosphoenolpyruvate carboxykinase for decarboxylation. CAM plants use a functional analogue of these systems, typically involving both types of malic enzymes separated.

86. (A) An enlarged vacuole for nocturnal malic acid storage
CAM plants separate the initial fixation of carbon dioxide and the Calvin cycle temporally within a single cell. This unique strategy is enabled by the presence of a large central vacuole, which serves as a storage reservoir for malic acid accumulated during the night. The daytime decarboxylation of this acid then provides a concentrated source of carbon dioxide for Rubisco.

87. (B) It stabilizes the manganese cluster of the oxygen-evolving complex
The PsbO protein is an essential extrinsic subunit of the Photosystem II complex, often referred to as the manganese-stabilizing protein. It is located on the lumenal side of the thylakoid membrane and plays a critical role in stabilizing the manganese cluster within the oxygen-evolving complex. By maintaining the structural integrity of this cluster, PsbO ensures the efficient oxidation of.

88. (D) High light intensity, high temperature, and water limitation
C4 plants exhibit a significant physiological advantage over C3 plants under specific environmental stresses. Due to their carbon-concentrating mechanism, they can maintain high rates of photosynthesis even when stomata are partially closed to conserve water. This makes them particularly well-adapted to environments characterized by high light intensity, elevated

71. (B) Monogalactosyldiacylglycerol (MGDG)
The thylakoid membrane is characterized by a high concentration of specialized galactolipids rather than typical phospholipids. Monogalactosyldiacylglycerol is the most abundant lipid species within this membrane system. Due to its unique cone-shaped structure, MGDG is essential for maintaining the non-bilayer properties and high curvature needed for the organization of grana stacks and the stability of large photosynthetic protein complexes.

72. (A) Light-Harvesting Complex II (LHCII)
In higher plants, the Light-Harvesting Complex II serves as the primary antenna system for Photosystem II. It is composed of multiple proteins and a dense array of chlorophyll a, chlorophyll b, and xanthophyll pigments. LHCII is responsible for capturing solar energy and funneling it toward the reaction center, playing a critical role in both light harvesting and photoprotective regulation.

73. (A) It binds the reaction center chlorophyll and redox cofactors
The D1 protein is a core subunit of the Photosystem II reaction center heterodimer. It provides the essential structural framework for binding the P680 reaction center chlorophylls and several key redox cofactors, including pheophytin and plastoquinone. Because it is highly susceptible to photo-oxidative damage, the D1 protein undergoes a continuous cycle of degradation and repair to maintain photosynthetic function.

74. (C) Splitting of water to release molecular oxygen
Photosystem I is a multi-protein complex that functions as a plastocyanin-ferredoxin oxidoreductase, absorbing far-red light to generate a strong reductant. However, it does not possess the capacity to split water or release molecular oxygen. Water oxidation is a function uniquely performed by the oxygen-evolving complex associated with Photosystem II. Therefore, oxygen release is not a process that occurs within.

75. (A) III, IV, II, I
The chloroplast envelope is a complex double-membrane system that separates the stroma from the surrounding cytosol. When moving from the exterior of the organelle toward the interior, one first encounters the outer envelope membrane. This is followed by the intermembrane space and then the highly selective inner envelope membrane. Finally, the interior fluid-filled compartment, known as the stroma, is.

76. (A) Transfer electrons and protons from PSII to the cytochrome b6f complex
Plastoquinone is a lipophilic electron carrier that resides within the thylakoid lipid bilayer. Its primary physiological role is to facilitate the transfer of electrons and protons between Photosystem II and the cytochrome b6f complex. By accepting electrons from the reaction center and protons from the stroma, it becomes reduced to plastoquinol, which then diffuses through the membrane to deliver its.

77. (B) Cyclic electron transport around Photosystem I
The PGR5-dependent pathway is one of the two primary routes for cyclic electron transport around Photosystem I. This pathway facilitates the redirection of electrons from ferredoxin back to the plastoquinone pool, bypassing the formation of NADPH. This process is essential for maintaining the correct ATP to NADPH ratio and protecting the photosynthetic apparatus from damage by regulating the.

78. (C) It is dominated by the Delta pH component in steady-state
The light reactions of photosynthesis establish a proton motive force across the thylakoid membrane. This force consists of both a chemical pH gradient and an electrical potential. Under steady-state conditions, the electrical component is largely dissipated by the movement of other ions, making the ΔpH the dominant contributor. This gradient drives the synthesis of ATP as protons move back.

79. (A) Activating key Calvin cycle enzymes such as Rubisco
The light-induced movement of protons into the thylakoid lumen is accompanied by the efflux of magnesium ions into the stroma. This increase in stromal magnesium concentration is critical for the activation of several essential Calvin cycle enzymes, most notably Rubisco. By serving as a necessary cofactor, magnesium ensures that carbon fixation is efficiently coupled to the availability of light energy.

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this excess energy safely as heat, beta-carotene prevents the degradation of membranes and.

98. (D) Trimer
Light-Harvesting Complexes are organized into specific structural units to optimize light absorption and energy transfer. The predominant antenna complex associated with Photosystem II in higher plants is a trimer. Each monomer within the trimer binds numerous chlorophyll and carotenoid molecules, creating a robust and efficient system for capturing solar energy and delivering it to the reaction center.

99. (B) S4
The Oxygen-Evolving Complex of Photosystem II undergoes a cycle of five distinct oxidation states, known as S_0 through S_4. As the complex absorbs photons, it sequentially accumulates positive charges. The S_4 state is the most oxidized and transient intermediate in this cycle. Upon reaching this state, the complex reacts with water molecules, releasing molecular oxygen and returning.

100. (A) I, II and IV
Photosystem I functions as a plastocyanin-ferredoxin oxidoreductase, transferring electrons from the thylakoid lumen to the stroma. Its reaction center core is composed of two large subunits, PsaA and PsaB. During the light reactions, the primary electron acceptor is a specific chlorophyll a molecule designated as A0. While it can participate in both linear and cyclic electron flow, its basic.

101. (B) 8
In the Z-scheme of electron transport, the production of one molecule of molecular oxygen requires the extraction of four electrons from two water molecules. Since each electron must be energized twice, once at Photosystem II and once at Photosystem I, a total of eight photons must be absorbed globally by the two photosystems to complete this process.

102. (B) It donates electrons to the plastoquinone pool
During cyclic photophosphorylation, the flow of electrons is redirected to focus solely on ATP production. Instead of transferring electrons to $NADP^+$, reduced ferredoxin donates them back to the plastoquinone pool, often via the cytochrome b6f complex or a specific reductase. This cyclic movement generates a proton gradient that drives ATP synthesis without the simultaneous reduction of $NADP^+$ to NADPH.

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103. (B) 3 to 4.7
The synthesis of one molecule of ATP by the chloroplast CF0-CF1 complex requires the translocation of a specific number of protons through the membrane. Based on the structural stoichiometry of the c-ring, which typically contains 14 subunits in chloroplasts, approximately 4.7 protons must pass through the synthase to drive one full rotation and produce three ATP molecules.

104. (C) Excess Red light (preferentially exciting PSII)
A transition to State 2 occurs when Photosystem II is preferentially excited, leading to an over-reduction of the plastoquinone pool. This condition typically arises under excess red light. The over-reduced state activates the STN7 kinase, which phosphorylates the Light-Harvesting Complex II. Consequently, LHCII migrates from the appressed grana regions to the unstacked stroma lamellae to associate with.

105. (C) IV
The Calvin-Benson cycle consists of carboxylation, reduction, and regeneration phases. While it consumes three ATP and two NADPH molecules per molecule of carbon dioxide fixed, the reduction phase specifically produces glyceraldehyde-3-phosphate rather than 3-phosphoglycerate. In fact, 3-phosphoglycerate is the reactant for the reduction phase, not the product. Therefore, claiming that the reduction phase yields 3-phosphoglycerate is incorrect.

106. (A) Carbamylated and bound to Mg^{2+}
For Rubisco to be catalytically active, a specific lysine residue within its active site must undergo a necessary modification. This process involves the non-catalytic addition of a carbon dioxide molecule to form a carbamate, followed by the binding of a magnesium ion. This carbamylated state, stabilized by magnesium, is essential for the enzyme to properly bind ribulose-1,5-bisphosphate and.

107. (A) Rubisco and fructose-1,6-bisphosphatase
During active photosynthesis, light-driven proton pumping into the thylakoid lumen causes the pH of the stroma to increase from approximately 7.0

to 8.0. This alkalization is vital because several key Calvin cycle enzymes, including Rubisco and fructose-1,6-bisphosphatase, have alkaline pH optima for maximum catalytic activity. This change ensures that carbon fixation is efficiently synchronized with the availability.

108. (A) Phosphoenolpyruvate
In C4 Hatch-Slack pathway, mesophyll cells serve as the site for the initial capture of inorganic carbon. The enzyme PEP carboxylase catalyzes the carboxylation of phosphoenolpyruvate, which acts as the primary carbon acceptor. This reaction produces the four-carbon organic acid oxaloacetate in the cytosol. This mechanism effectively bypasses the oxygenase activity of Rubisco, which is located in the.

109. (D) Stomata close, malate decarboxylates, and CO2 rises
Phase III of Crassulacean Acid Metabolism occurs during the daylight hours when the stomata are closed to conserve water. During this period, the malate stored in the vacuole is transported back to the cytosol and decarboxylated. This process releases a high concentration of carbon dioxide internally, which is then utilized by Rubisco in the Calvin cycle to produce.

110. (A) Glycolate oxidase
Within the photorespiratory cycle, glycolate oxidase is a key enzyme located in the peroxisome. It catalyzes the oxidation of glycolate to glyoxylate using molecular oxygen. A significant byproduct of this specific reaction is hydrogen peroxide, which is a potentially toxic reactive oxygen species. To protect the cell, the enzyme catalase is also present in the peroxisome to rapidly.

111. (D) $5ATP{:}2NADPH$
The C4 photosynthetic pathway is more energy-intensive than the C3 pathway because it involves an additional CO_2-concentrating step. In standard NADP-ME type C4 plants, fixing one molecule of carbon dioxide requires the consumption of five ATP molecules and two NADPH molecules. This increased energetic cost is the trade-off for virtually eliminating photorespiration and maintaining high productivity in hot, bright.

112. (A) Synthetic enzymes activation and degradative inhibition
To prevent a futile cycle of simultaneous starch synthesis and degradation, plants utilize strict regulatory controls. During the day, enzymes involved in starch synthesis are allosterically activated by metabolic intermediates, while degradative enzymes are inhibited. This ensures that carbon is stored when photosynthetic output is high. At night, these regulatory signals reverse, allowing for the controlled breakdown of starch.

113. (B) It stalls as triose phosphates cannot exit
The triose phosphate/phosphate translocator facilitates the movement of carbon between the chloroplast and the cytosol. Because this translocator operates as a strict antiporter, the export of triose phosphates requires the simultaneous import of inorganic phosphate. If cytosolic phosphate levels drop significantly, the transport process stalls. This leads to an accumulation of products in the stroma and a.

114. (A) Activation by glucose-6-phosphate and inhibition by inorganic phosphate (Pi)
Sucrose-phosphate synthase is a primary control point for sucrose biosynthesis in the plant cytosol. Its activity is sensitive to the levels of metabolic intermediates that signal the energy and carbon status of the cell. Specifically, the enzyme is allosterically activated by glucose-6-phosphate, which indicates high carbon availability, and is inhibited by inorganic phosphate, which signals low energy.

115. (A) P-3, Q-4, R-2, S-1
Starch biosynthesis in plastids involves several specialized enzymes working in coordination. Phosphoglucomutase converts glucose-6-phosphate into glucose-1-phosphate, which is then used by ADP-glucose pyrophosphorylase to synthesize the activated precursor ADP-glucose. Starch synthase elongates the glucan chains, and the branching enzyme introduces alpha-1,6-glycosidic linkages to create the characteristic structure of amylopectin. Together, these enzymes ensure the efficient storage.

116. (B) Coat lipid bodies to prevent coalescence
Oleosins are specialized structural proteins found on the surface of lipid bodies, or oleosomes, in seeds. Their primary function is to form a protective coating that prevents the

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individual oil droplets from coalescing into larger masses during periods of seed dehydration and rehydration. By maintaining a high surface-area-to-volume ratio, oleosins ensure that storage lipids are easily accessible to.

117. (A) Micromoles of photons per square meter per second
In plant physiology, Photosynthetically Active Radiation is most accurately quantified using the concept of photon flux density. The standard unit for measuring this parameter is micromoles of photons per square meter per second. This unit reflects the fact that photosynthesis is a quantum process driven by the number of absorbed photons rather than the total amount of energy.

118. (B) It exhibits extreme lateral heterogeneity
The thylakoid membrane system in chloroplasts exhibits extreme lateral heterogeneity in the distribution of its major protein complexes. Photosystem II and its associated light-harvesting antenna are predominantly located within the appressed regions of the grana stacks. In contrast, Photosystem I and ATP synthase are restricted to the non-appressed stroma lamellae and grana margins, facilitating specialized roles in electron.

119. (B) It anchors the chlorophyll molecule into the hydrophobic core of the thylakoid lipid bilayer
Chlorophyll molecules consist of a light-absorbing porphyrin ring and a long, hydrophobic phytol tail. This hydrocarbon chain is essential for the function of the pigment because it anchors the chlorophyll molecule securely into the hydrophobic core of the thylakoid membrane's lipid bilayer. This orientation ensures that the pigments are correctly positioned for efficient energy transfer and electron transport.

120. (C) Energy moves downhill toward the reaction center
Resonance energy transfer is the primary mechanism by which solar energy is funneled through antenna pigments toward the reaction center. This process is characterized by the transfer of excitation energy between adjacent molecules through dipole-dipole interactions. To ensure efficiency, the energy movement occurs in a "downhill" manner, from pigments that absorb shorter wavelengths to those that absorb longer.

121. (D) Carry electrons between the OEC and $P680^+$
Tyrosine-Z is a critical redox-active amino acid residue located within the D1 protein of the Photosystem II reaction center. It serves as an essential intermediary in the electron transport chain, carrying electrons from the oxygen-evolving complex to the oxidized reaction center pigment, $P680^+$. This rapid electron transfer is vital for maintaining the continuous operation of the water-splitting process.

122. (A) Chlorophyll a molecules (specifically, a heterodimer of Chl a and Chl a')
The reaction center of Photosystem I contains a specialized pigment pair known as P700, which serves as the primary electron donor. This structure is composed of a dimer of chlorophyll a molecules, specifically a heterodimer of chlorophyll a and its epimer, chlorophyll a'. Upon absorbing light energy, P700 reaches an excited state and releases an electron to.

123. (B) 2
The operation of the Q-cycle within the cytochrome b6f complex significantly increases the efficiency of proton translocation across the thylakoid membrane. For every pair of electrons that pass through the complex, two molecules of plastoquinol are oxidized at the lumen-side binding site. This process leads to the net translocation of four protons into the lumen, doubling the proton.

124. (A) High ratio of NADPH to $NADP^+$ in the stroma
Cyclic electron transport around Photosystem I is often upregulated in response to specific metabolic conditions within the stroma. A high ratio of NADPH to $NADP^+$ signals that the Calvin cycle is saturated with reducing power and requires additional ATP. By shifting to the cyclic pathway, the plant can continue to generate a proton gradient for ATP synthesis.

125. (B) Protons travel through CF0, driving rotor rotation
The synthesis of ATP by the chloroplast synthase is a complex mechanical process driven by the movement of protons. Protons travel from the thylakoid lumen to the stroma through the CF0 portion of the enzyme. This downward flow drives the rotation of the rotor subunits, which induces conformational changes in the catalytic sites of the CF1 unit, allowing.

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transfer of electrons from reduced ferredoxin to $NADP^+$, producing the NADPH necessary for the reduction phase of the.

145. (A) Cytochrome b6f complex
The Rieske iron-sulfur protein is a critical component for photosynthetic electron transport. It is physically located within the cytochrome b6f complex, which is an integral membrane protein spanning the thylakoid bilayer. This protein is essential for the oxidation of plastoquinol and the subsequent transfer of electrons toward cytochrome f, playing a vital role in coupling electron.

146. (A) High ATP demand and low $NADP^+$
Cyclic electron transport is most strongly upregulated under metabolic conditions where there is a high demand for ATP relative to the availability of $NADP^+$. When NADPH levels are high and the stroma is depleted of $NADP^+$ linear electron flow is restricted. Shifting to the cyclic pathway allows the plant to continue generating a proton motive force.

147. (A) Impermeable to protons to maintain the gradient
The chemiosmotic coupling of electron transport to ATP synthesis strictly requires a thylakoid membrane that is selectively impermeable to protons. This impermeability is essential for maintaining the electrochemical proton gradient established by the light reactions. Any significant leakage of protons across the lipid bilayer would dissipate the proton motive force, preventing the ATP synthase from utilizing the.

148. (A) It maintains electroneutrality during pumping
During light-driven electron transport, the influx of chloride ions into the thylakoid lumen plays a secondary but important role. As protons are actively pumped into the lumen, the movement of chloride ions helps to maintain electroneutrality and balance the resulting electrical charge. This prevents the buildup of an excessive electrical potential that would otherwise inhibit the continued.

149. (C) 6
To achieve a net gain of one six-carbon sugar molecule, such as glucose or fructose, the Calvin-Benson cycle must fix six molecules of atmospheric carbon dioxide. This process requires six complete turns of the cycle, consuming a total of eighteen molecules of ATP and twelve molecules of NADPH. This investment ensures the regeneration of the carbon dioxide.

150. (A) It is composed of 8 large subunits (L8) and 8 small subunits (S8)
Form I Rubisco is the specific structural variant found in almost all photosynthetic eukaryotes, including higher plants. This enzyme is a large multi-subunit complex characterized by an L8S8 arrangement. It consists of eight large catalytic subunits, which are encoded by the chloroplast genome, and eight small regulatory subunits, which are encoded by the nuclear genome and imported into the.

151. (C) Rubisco
While many Calvin cycle enzymes are regulated by the ferredoxin-thioredoxin system, Rubisco is a notable exception to this specific mechanism. Its activity is primarily controlled by the action of Rubisco activase and the process of carbamylation. Although it responds to the light-induced changes in the stroma, such as increased magnesium and alkaline pH, it does not require thioredoxin-mediated.

152. (A) Aspartate
In C4 plants belonging to the NAD-malic enzyme subtype, the transport of fixed carbon between different cell types involves specialized organic acids. Aspartate is the primary metabolite that moves from the mesophyll cells to the bundle sheath cells. Once inside the bundle sheath mitochondria, aspartate is converted back into malate, which is then decarboxylated to release carbon dioxide.

153. (A) The membrane must be selectively impermeable to protons
C4 plants are highly efficient in their carbon fixation, which allows them to maintain productivity under conditions that would cause severe stress in C3 plants. However, this efficiency is tied to a specific set of environmental adaptations. C4 species are generally optimized for high-growth environments where light and temperature are abundant, often demonstrating higher water-use efficiency despite the.

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135. (B) Photorespiratory ammonia reassimilation
The coordination of carbon and nitrogen assimilation requires the continuous exchange of metabolites across the chloroplast envelope. The movement of 2-oxoglutarate and glutamate is facilitated by a specialized dicarboxylate translocator. This exchange is particularly crucial for the photorespiratory cycle and the subsequent reassimilation of ammonia, ensuring that nitrogen is efficiently recycled and integrated into amino acids within the.

136. (C) Sucrose
Sucrose is the dominant form of photoassimilate exported from source leaves to various sink tissues in most higher plants. As a non-reducing sugar, it is chemically stable and can be transported at high concentrations through the phloem. This allows for the efficient delivery of energy and carbon skeletons to non-photosynthetic organs such as roots, fruits, and.

137. (A) Isoamylase (Debranching enzyme)
The degradation of transient starch granules in the chloroplast is a complex process involving several types of enzymes. While amylases break down the linear glucan chains, the removal of branch points is required for complete hydrolysis. The enzyme isoamylase, also known as the debranching enzyme, specifically catalyzes the cleavage of alpha-1,6-glycosidic linkages. This activity allows other enzymes to.

138. (C) Prolamins
In the endosperm of most cereal grains, such as wheat and maize, the majority of storage reserves are deposited as specialized proteins called prolamins. These proteins are characterized by their high content of proline and glutamine and their unique solubility properties. They are synthesized and stored within protein bodies to provide the necessary nitrogen and amino acids.

139. (A) Through the use of accessory pigments
Plants can effectively utilize a wide range of light wavelengths by employing a diverse array of accessory pigments. Molecules such as chlorophyll b and various carotenoids absorb light in regions where chlorophyll a is less effective. Through resonance energy transfer, these pigments funnel the captured excitation energy toward the reaction centers, thereby maximizing the total solar energy.

140. (C) The thylakoid lumen
During active steady-state photosynthesis, the thylakoid lumen becomes the most acidic sub-compartment of the chloroplast. This acidity results from the light-driven pumping of protons by the electron transport chain and the release of protons during water oxidation. The resulting proton gradient across the thylakoid membrane establishes the necessary electrochemical potential used by ATP synthase to produce.

141. (B) They serve only to expand the action spectrum
Carotenoids are essential pigments synthesized in plastids through the methylerythritol phosphate pathway. While they do broaden the action spectrum of photosynthesis by absorbing blue light, they perform several other vital functions. Most importantly, they are indispensable for photoprotection, quenching triplet chlorophyll and singlet oxygen to prevent damage. Therefore, claiming that they serve only to expand the.

142. (A) Chlorophyll a, b, and xanthophylls
The structural and functional integrity of the Light-Harvesting Complex II depends on its specific pigment-binding properties. A typical monomer of this complex binds multiple molecules of chlorophyll a and chlorophyll b, along with various xanthophylls like lutein and neoxanthin. These pigments are precisely oriented to facilitate efficient energy capture and transfer, while also participating in vital photoprotective.

143. (B) It receives an excited electron directly from P680 before transferring it to tightly bound quinones
Pheophytin is a specialized chlorophyll molecule that lacks the central magnesium ion and acts as the primary electron acceptor in Photosystem II. Following the excitation of the reaction center pigment P680, an electron is transferred directly to pheophytin. This rapid charge separation is the first step in the conversion of light energy into chemical energy, preceding electron transfer.

144. (B) $NADP^+$
In the linear, non-cyclic electron transport chain of chloroplasts, electrons flow from water through both photosystems to eventually reach a final carrier. $NADP^+$ serves as the terminal electron acceptor in this pathway. The enzyme ferredoxin-$NADP^+$ reductase catalyzes the final

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126. (B) Balance the excitation energy distribution evenly between PSII and PSI
State transitions function as a short-term regulatory mechanism that allows plants to adapt to changing light qualities. By reversibly redistributing the Light-Harvesting Complex II between the two photosystems, the plant can balance the absorption of excitation energy. This ensures that both Photosystem II and Photosystem I operate at similar rates, preventing bottlenecks in the electron transport chain and.

127. (A) Two-carbon units between sugar phosphates
During the regeneration phase of the Calvin-Benson cycle, the enzyme transketolase plays a vital role in reorganizing carbon skeletons. It catalyzes the reversible transfer of a two-carbon ketol group from a ketose donor to an aldose acceptor. This activity is essential for interconverting various sugar phosphates, allowing the cycle to efficiently reconstruct ribulose-1,5-bisphosphate from the triose phosphate products.

128. (B) About 20-25%
Rubisco naturally reacts with both carbon dioxide and oxygen, and the relative rates of these reactions depend on the atmospheric concentration of the gases. In typical C3 plants at a temperature of 25 degrees Celsius, approximately 20 to 25 percent of the enzyme's reactions involve oxygenation rather than carboxylation. This leads to the initiation of the photorespiratory cycle.

129. (C) Thioredoxin
The activation of sedoheptulose-1,7-bisphosphatase is a key step in the light-dependent regulation of the Calvin cycle. This enzyme contains critical internal disulfide bonds that must be reduced to sulfhydryl groups for catalytic activity. Upon illumination, the ferredoxin-thioredoxin system facilitates this reduction. Specifically, the protein thioredoxin serves as the direct electron donor, modifying the enzyme's structure to its.

130. (A) Both A and R are true and R is the correct explanation of A.
C4 plants have evolved a specialized Kranz anatomy that is fundamental to their high photosynthetic efficiency. This structural arrangement physically separates the initial fixation of carbon dioxide in mesophyll cells from the Calvin cycle in bundle sheath cells. This spatial organization prevents Rubisco from interacting with atmospheric oxygen, thereby minimizing wasteful photorespiration and allowing the enzyme to.

131. (A) Breakdown of storage carbohydrates via glycolysis
In Crassulacean Acid Metabolism, the initial fixation of carbon dioxide at night requires a steady supply of phosphoenolpyruvate. This three-carbon substrate is primarily derived from the breakdown of storage carbohydrates, such as starch or glucans, through the glycolytic pathway. This nocturnal mobilization of carbon reserves ensures that PEP carboxylase can continuously produce the malate needed for storage.

132. (B) 3
The production of a net gain of one six-carbon sugar equivalent from the Calvin cycle requires multiple turns and significant carbon input. To yield one molecule of dihydroxyacetone phosphate, which is a three-carbon sugar, the cycle must fix three molecules of atmospheric carbon dioxide. This process consumes nine molecules of ATP and six molecules of NADPH to.

133. (A) Conserve water without limiting CO_2 fixation
C4 plants possess a distinct physiological advantage in arid environments due to their highly efficient carbon-concentrating mechanism. This system allows them to maintain high internal concentrations of carbon dioxide around Rubisco, even when stomata are partially closed to reduce transpiration. Consequently, C4 plants can continue to fix carbon at high rates while significantly conserving water compared to C3.

134. (B) Triose phosphate/phosphate translocator (TPT)
The triose phosphate/phosphate translocator is the primary transport protein responsible for exporting the products of photosynthesis from the chloroplast. Located in the inner envelope membrane, it facilitates the movement of triose phosphates into the cytosol in exchange for inorganic phosphate. This exported carbon then serves as the substrate for sucrose biosynthesis, which is essential for transporting energy.

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154. (A) A specific glycolate/glycerate translocator in the inner envelope
During the photorespiratory cycle, the move of metabolic intermediates between organelles is facilitated by specific transport proteins. Glycolate produced in the chloroplast must be moved to the peroxisome for further processing. This is achieved by a dedicated glycolate/ glycerate translocator located in the inner chloroplast envelope. This transporter allows for the efficient exchange of glycolate for glycerate, continuing the.

155. (A) C4 pathway
Different photosynthetic pathways exhibit characteristic patterns of carbon isotope discrimination. C4 plants show significantly lower discrimination against the heavier 13C isotope compared to C3 plants, resulting in less negative $\delta^{13}C$ values. This difference arises because the enzyme PEP carboxylase, which performs the initial fixation in C4 plants, does not discriminate between carbon isotopes as strongly as.

156. (A) Maltose
At night, the transient starch accumulated in chloroplasts during the day is broken down to provide carbon for the rest of the plant. The primary product of this degradative process is the disaccharide maltose. Maltose is then exported from the chloroplast stroma to the cytosol via a specialized maltose transporter. Once in the cytosol, it is further.

157. (A) The malate-oxaloacetate shuttle
The malate-oxaloacetate shuttle is a critical mechanism for the indirect export of reducing power from the chloroplast. Since $NADP^+$ and NADPH are unable to cross the inner envelope membrane, the shuttle uses the reversible reduction of oxaloacetate to malate. This process allows reducing equivalents generated during the light reactions to be moved to the cytosol, supporting various essential.

158. (A) Sucrose-6-phosphate and free UDP
Sucrose-phosphate synthase catalyzes the first committed step in the biosynthesis of sucrose within the plant cytosol. The enzyme uses UDP-glucose and fructose-6-phosphate as its substrates to produce sucrose-6-phosphate and free UDP. This reaction is a key control point, as the subsequent dephosphorylation of sucrose-6-phosphate by sucrose-phosphate phosphatase makes the overall process irreversible and ensures the steady production.

159. (A) Amylose (linear) and Amylopectin (highly branched)
Starch granules in plant plastids are composed of two distinct glucose polymers that differ in their structure and properties. Amylose is a largely linear polymer consisting of alpha-1,4-glycosidic linkages. In contrast, amylopectin is a highly branched polymer that contains both alpha-1,4 and alpha-1,6-glycosidic linkages. The relative proportion and organization of these two polymers determine the semi-crystalline nature of.

160. (A) Glycerol-3-phosphate
Triacylglycerols are the primary storage lipids in seeds, consisting of three fatty acids esterified to a glycerol backbone. The direct biochemical precursor for this backbone is glycerol-3-phosphate. This molecule is derived from the glycolytic intermediate dihydroxyacetone phosphate through a reduction reaction. Glycerol-3-phosphate provides the structural framework onto which fatty acids are sequentially added by various acyltransferase enzymes during.

161. (A) 680 nm
The red drop effect refers to a sharp decline in the quantum yield of photosynthesis when plants are exposed to light wavelengths longer than approximately 680 nanometers. This phenomenon occurs because these far-red wavelengths are primarily absorbed by Photosystem I and are insufficient to drive Photosystem II. Since both photosystems must operate in series for efficient photosynthesis, the overall.

162. (A) By separating PSII grana from PSI stroma
The internal architecture of the chloroplast utilizes lateral heterogeneity to manage energy distribution between the two photosystems. By segregating Photosystem II within the appressed regions of the grana and Photosystem I in the unstacked stroma lamellae, the plant prevents energy spillover from PSII to PSI. This organization allows the two systems to function semi-independently and be regulated according to.

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202. (A) Fructose-2,6-bisphosphate (F2,6BP)
Cytosolic fructose-1,6-bisphosphatase is a critical enzyme that regulates the flow of carbon toward sucrose synthesis. Its activity is tightly controlled by the regulatory metabolite fructose-2,6-bisphosphate. When the concentration of F2,6BP is high, it potently inhibits the enzyme, effectively slowing down sucrose production. This regulatory mechanism allow the plant to adjust its carbon partitioning based on the metabolic.

203. (A) Starch Branching Enzyme (SBE)
The synthesis of amylopectin, the highly branched component of starch, requires the coordinated action of multiple enzymes. While starch synthase is responsible for elongating the linear alpha-1,4-linked glucan chains, the formation of branch points depends on the starch branching enzyme. SBE catalyzes the introduction of alpha-1,6-glycosidic linkages, creating the complex architecture necessary for the dense storage of carbon within.

204. (A) The secretory pathway (ER → Golgi → PSV)
Storage proteins in developing seeds are synthesized on the rough endoplasmic reticulum and must be correctly directed to their final destination. These proteins follow the classical secretory pathway, moving from the ER to the Golgi apparatus. From the Golgi, they are sorted into specialized vesicles that transport them to the protein storage vacuole. This precise trafficking ensures that reserves.

205. (A) Reflects or transmits green light
The characteristic green color of leaves is a direct consequence of the light-absorbing properties of chlorophyll pigments. Chlorophyll a and chlorophyll b absorb solar energy most effectively in the blue and red regions of the visible spectrum. However, they are much less efficient at absorbing green light. As a result, green wavelengths are predominantly reflected or transmitted by the.

206. (A) Circular DNA and 70S ribosomes
Chloroplasts are widely believed to have originated from an ancient endosymbiotic event involving a photosynthetic cyanobacterium. This theory is strongly supported by several bacterial-like features retained by the organelle. Most notably, chloroplasts possess their own circular DNA and 70S ribosomes, which are much more similar to those of prokaryotes than to the linear chromosomes and 80S ribosomes found in.

207. (A) Protoporphyrin IX
The biosynthesis of porphyrins is a branched pathway that leads to the production of several essential cofactors. Protoporphyrin IX represents the final common intermediate before the pathway diverges into two major branches. The insertion of an iron ion by ferrochelatase leads to the synthesis of heme, while the insertion of a magnesium ion by magnesium-chelatase commits the pathway.

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208. (A) Zeaxanthin
The xanthophyll cycle is a critical photoprotective mechanism that helps plants manage excessive light energy. Under high light stress, the enzyme violaxanthin de-epoxidase converts violaxanthin into zeaxanthin. The accumulation of zeaxanthin in the thylakoid membrane facilitates the safe dissipation of excess excitation energy as heat, thereby protecting the photosynthetic apparatus from oxidative damage.

209. (A) $S_3 \rightarrow S_4 \rightarrow S_0$
The Kok cycle describes how the oxygen-evolving complex accumulates the four oxidizing equivalents needed to split water. This process involves five states, S_0 through S_4. The transition from S_3 to S_4 occurs upon the absorption of the fourth photon. The S_4 state is highly unstable and immediately reacts with water to release molecular oxygen, simultaneously returning the manganese.

210. (C) It requires manganese to function
Photosystem I is a large protein complex that functions as a plastocyanin-ferredoxin oxidoreductase. It features a P700 reaction center and utilizes a series of iron-sulfur centers and a primary chlorophyll acceptor, A0. However, it does not require manganese for its catalytic activity. Manganese is a unique requirement for the water-splitting complex associated with Photosystem II. Therefore, claiming PSI.

211. (A) -1.2 V
In the Z-scheme of photosynthesis, the excitation of the P680 reaction center in Photosystem II produces an extremely strong reductant. The midpoint redox potential of this excited state, P680, is approximately -1.2 volts. This highly negative potential is necessary to drive the rapid

higher affinity for its substrate, meaning it can achieve half-maximum velocity at a.

173. (A) Cysteine
The ferredoxin-thioredoxin system regulates the activity of several Calvin cycle enzymes through reversible redox modifications. This control mechanism specifically targets pairs of cysteine residues within the enzymes. Upon receiving electrons from thioredoxin, these cysteine residues are converted from a disulfide bond to reduced sulfhydryl groups. This change in redox state induces a conformational shift that either activates or deactivates.

174. (A) ATP, yielding AMP and PPi
Pyruvate, phosphate dikinase is an essential enzyme in the C4 pathway, responsible for regenerating the primary carbon acceptor, phosphoenolpyruvate. This reaction occurs in the mesophyll chloroplasts and uniquely consumes one molecule of ATP. Interestingly, the enzyme converts ATP into AMP and inorganic pyrophosphate, a high-energy cleavage that provides the necessary thermodynamic drive to convert pyruvate back into PEP.

175. (A) Phase I (Night)
In Crassulacean Acid Metabolism, the primary uptake and fixation of atmospheric carbon dioxide occur during Phase I, which corresponds to the nocturnal period. Because stomata are open during the cool night, PEP carboxylase can efficiently fix carbon dioxide into oxaloacetate, which is then reduced to malate. This strategy allows the plant to accumulate carbon while significantly reducing water loss.

176. (A) Glutamate or Serine
Within the photorespiratory cycle, the peroxisome is the site of a critical transamination reaction. The enzyme glyoxylate aminotransferase converts glyoxylate into the amino acid glycine. This reaction requires a nitrogen donor, which is typically provided by glutamate or serine. This step is essential for moving carbon forward in the scavenger pathway and ensuring that amino groups are.

177. (A) Uptake rate exactly equals release rate
The carbon dioxide compensation point is a fundamental physiological parameter that describes the balance of gas exchange in a leaf. It is defined as the specific atmospheric concentration of carbon dioxide at which the rate of photosynthetic uptake exactly equals the rate of respiratory and photorespiratory release. At this point, the net exchange of carbon dioxide with the environment.

178. (A) Cytosolic sucrose synthesis impairment
A defect in the triose phosphate/phosphate translocator within a mature leaf would have immediate and severe metabolic consequences. Because the TPT is responsible for exporting triose phosphates to the cytosol, sucrose synthesis would be significantly impaired. Concurrently, the accumulation of products in the stroma would lead to a depletion of inorganic phosphate, eventually stalling the Calvin cycle and.

179. (A) Malate and alpha-ketoglutarate
The dicarboxylate translocator is a specialized transport protein located in the inner chloroplast envelope. It plays a key role in metabolic integration by facilitating the exchange of specific organic acids between the stroma and the cytosol. This transporter is primarily responsible for moving malate and alpha-ketoglutarate, which are essential for maintaining redox balance and supporting nitrogen assimilation within the.

180. (A) Sucrose synthase
In various plant sink tissues, the enzyme sucrose synthase plays a major role in the initial breakdown of imported sucrose. Although it is capable of synthesis, its physiological function in these tissues is to catalyze the reversible cleavage of sucrose into fructose and UDP-glucose. This reaction provides activated glucose and fructose for various metabolic pathways, including cell wall synthesis.

181. (A) Inorganic phosphate (Pi)
The regulation of starch biosynthesis in plastids is controlled by the activity of the enzyme ADP-glucose pyrophosphorylase. This enzyme is highly sensitive to the energy status of the cell and the availability of carbon. While it is allosterically activated by 3-phosphoglycerate, it is potently inhibited by inorganic phosphate. This ensures that starch synthesis is restricted when phosphate.

182. (A) Hexose phosphates or ADP-glucose
Amyloplasts are specialized non-pigmented plastids that serve as the primary site for long-term starch storage in organs such as seeds

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163. (A) Heme
The biosynthesis of phycobilins in cyanobacteria and certain algae is closely related to the chlorophyll pathway. These pathways share common early steps up to the formation of protoporphyrin IX. From this point, the phycobilin branch diverges through the formation of heme and its subsequent oxidative cleavage. The resulting biliverdin IX-alpha serves as the precursor for the synthesis of.

164. (A) Heat
Non-photochemical quenching is a vital photoprotective mechanism that allows plants to cope with excessive light levels. This process prevents damage to the photosynthetic apparatus by safely dissipating excess excitation energy from the antenna systems as harmless heat. This thermal dissipation is regulated by the xanthophyll cycle and the presence of specific proteins, ensuring that the plant avoids the.

165. (A) P-1, Q-2, R-4, S-3
Within Photosystem II, the transfer of electrons from the reaction center to the plastoquinone pool involves two distinct quinone molecules. Qa is a tightly bound plastoquinone that acts as a one-electron acceptor, while Qb is a loosely bound plastoquinone that functions as a two-electron and two-proton acceptor. Following its full reduction, Qb dissociates from the protein complex and.

166. (A) Plastocyanin
Plastocyanin is a small, water-soluble copper protein that resides in the thylakoid lumen. Its specific functional role is to serve as the immediate electron donor to the oxidized reaction center of Photosystem I. By delivering electrons from the cytochrome b6f complex to reduce P700+, plastocyanin ensures the continuous operation of the light-driven electron transport chain and the.

167. (A) Oxidation of water and plastoquinol
During the linear electron transport chain, protons are released into the thylakoid lumen at two specific locations. First, the oxidation of water molecules by the oxygen-evolving complex associated with Photosystem II releases four protons per molecule of oxygen produced. Second, the oxidation of plastoquinol at the cytochrome b6f complex also results in the translocation of protons from the.

168. (A) Photosystem II
Cyclic electron transport is a specialized pathway that recycles electrons around Photosystem I to generate additional ATP. This process differs from linear electron flow because it completely bypasses Photosystem II and the associated water-splitting complex. By recycling electrons through the cytochrome b6f complex, the plant can establish a proton motive force without the simultaneous production of NADPH or.

169. (A) ATP synthesis during acid-base transition
The chemiosmotic theory, proposed by Peter Mitchell, was definitively supported by a classic experiment involving an artificial acid-base transition in chloroplasts. When chloroplasts were equilibrated in an acidic medium and then suddenly transferred to a basic medium, they were able to synthesize ATP in total darkness. This demonstrated that a pH gradient alone is sufficient to drive ATP.

170. (A) Both A and R are true and R is the correct explanation of A.
Active photosynthesis causes the chloroplast stroma to become slightly alkaline as the pH increases. This change is driven by the light-dependent electron transport chain, which removes protons from the stroma to reduce NADP+ to NADPH. Concurrently, protons are actively pumped from the stroma into the thylakoid lumen. These processes create the electrochemical gradient necessary for ATP synthesis while.

171. (A) 3-Phosphoglycerate (3-PGA)
The carboxylation phase of the Calvin-Benson cycle begins with the reaction between carbon dioxide and ribulose-1,5-bisphosphate. This process produces an extremely unstable six-carbon intermediate that remains bound to the Rubisco enzyme. This intermediate is rapidly cleaved by hydrolysis into two identical molecules of the three-carbon compound, 3-phosphoglycerate. This reaction marks the first stable step in the assimilation.

172. (A) A higher affinity for the substrate
The affinity of Rubisco for its substrates is a critical factor in determining the rate of carbon fixation and photorespiration. This affinity is quantitatively described by the Michaelis constant, or K_m value. In enzymatic kinetics, a lower K_m value indicates that the enzyme has a

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significant structural modifications of the thylakoid membrane. The influx of protons into the lumen and the concurrent rise of magnesium in the stroma cause a tightening of grana appression. This more compact organization optimizes the distance between pigment-protein complexes, facilitating faster energy transfer and more efficient.

193. (A) 3 ATP and 0 NADPH
The regeneration phase of the Calvin-Benson cycle is essential for maintaining the continuous fixation of carbon dioxide. This process involves the conversion of five molecules of three-carbon glyceraldehyde-3-phosphate into three molecules of the five-carbon acceptor, ribulose-1,5-bisphosphate. This reconstruction requires the input of three molecules of ATP, provided by the light reactions, but notably does not consume any.

194. (A) Magnesium ion (Mg^{2+})
Measuring the activity of Rubisco in vitro requires precise conditions to ensure the enzyme is in its fully active state. Because the enzyme must be carbamylated and bound to a metal ion for catalysis, magnesium must be added to the assay medium. Magnesium stabilizes the carbamate on the active site lysine, allowing the enzyme to properly bind its.

195. (A) Endogenous oxidized redox systems
When plants are moved from light to darkness, the activity of several Calvin cycle enzymes must be rapidly suppressed to prevent the wasteful consumption of energy. This reversal of light-dependent activation is mediated by endogenous oxidized redox systems. In the absence of light-driven electron flow, the reduced sulfhydryl groups on the enzymes are re-oxidized to form disulfide bonds.

196. (A) Bundle sheath
Kranz anatomy is a specialized feature of C4 plants that facilitates efficient carbon fixation. In this arrangement, the vascular bundles are surrounded by a prominent, concentric layer of specialized bundle sheath cells. These cells have thickened walls and are often filled with large chloroplasts. This sheath layer is itself surrounded by mesophyll cells, creating a structural framework for.

197. (A) Restricted vacuolar malic capacity
While CAM photosynthesis is highly effective for water conservation, it is subject to several biochemical and physiological limitations. The most significant constraint is the restricted capacity of the central vacuole to store malic acid. This limitation determines the total amount of carbon that can be fixed during the night, which in turn limits the overall growth and productivity of.

198. (A) Glycerate (as 3-phosphoglycerate)
Photorespiration is often described as a scavenger pathway because its primary role is to recover carbon from the 2-phosphoglycolate produced by Rubisco's oxygenase activity. Through a series of reactions across three organelles, the pathway ultimately returns seventy-five percent of this carbon to the Calvin cycle in the form of 3-phosphoglycerate. This ensures that the plant minimizes the loss.

199. (A) Suberized layer in sheath walls
In C4 plants, the concentration of carbon dioxide within the bundle sheath cells is much higher than in the surrounding atmosphere. To prevent this concentrated gas from leaking back into the mesophyll, the bundle sheath cell walls often contain a specialized suberized layer. This layer acts as a diffusion barrier, maintaining the high internal carbon dioxide levels necessary for.

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200. (A) Oxidative pentose phosphate pathway
Nitrogen assimilation in the chloroplast stroma is a vital process that requires both energy and carbon skeletons. The oxidative pentose phosphate pathway serves as a primary source of these skeletons, providing the necessary organic acids to accept reduced nitrogen. This coordination between carbon and nitrogen metabolism ensures that amino acids are synthesized at a rate that matches the plant's.

201. (A) Nitrate reduction
The reduction of nitrate to ammonia in plant cells is a process that occurs in both the cytosol and the chloroplast. To support cytosolic nitrate reduction, the chloroplast utilizes the malate-oxaloacetate shuttle to export reducing equivalents. By providing a steady supply of NADH to the cytosol, the shuttle ensures that the enzyme nitrate reductase has the necessary power.

This ensures that the production of sugars and the regeneration of cycle intermediates occur only when light energy is.

240. (A) Pyruvate
In C4 plants of the NADP-malic enzyme subtype, the cycle involves the movement of specific metabolites between mesophyll and bundle sheath cells. After malate is decarboxylated in the bundle sheath chloroplasts to release carbon dioxide, the resulting pyruvate must be returned to the mesophyll cells. Once back in the mesophyll, pyruvate is used to regenerate the primary carbon.

241. (A) Water stress or salinity
Facultative CAM plants have the flexibility to switch between different photosynthetic pathways based on their environmental status. While they normally perform C3 photosynthesis, the induction of Crassulacean Acid Metabolism is typically triggered by water stress or high salinity. This adaptation allows the plant to conserve water by fixing carbon at night, ensuring survival and continued growth in.

242. (A) Chromoplasts
Chromoplasts are specialized, non-photosynthetic plastids that are primarily responsible for the synthesis and accumulation of carotenoid pigments. These organelles are found in high densities within the cells of flower petals and ripening fruits. The vibrant colors provided by chromoplasts serve important ecological roles, such as attracting pollinators and seed dispersers, while also serving as a reservoir for essential.

243. (A) C3 photorespiration rises with temperature
The photosynthetic efficiency of C3 plants declines significantly at high temperatures because the oxygenase activity of Rubisco increases more rapidly than its carboxylase activity, leading to higher rates of photorespiration. In contrast, C4 plants utilize a carbon-concentrating mechanism that saturates Rubisco with carbon dioxide, effectively suppressing oxygenation. This allows C4 plants to maintain high productivity even as temperatures rise.

244. (A) Triose phosphate utilization (TPU) limitation
When the rate of photosynthesis is limited by the plant's ability to utilize triose phosphates in the cytosol, it is known as triose phosphate utilization limitation. This often occurs when cytosolic inorganic phosphate levels become sequestered. Because the export of triose phosphates requires the import of phosphate, a lack of available phosphate stalls transport, eventually inhibiting the.

245. (A) Malate
The malate-oxaloacetate shuttle provides an essential pathway for moving reducing power between the chloroplast and the cytosol. Because pyridine nucleotides cannot cross the inner envelope, the shuttle utilizes malate and oxaloacetate as transport vehicles. In this system, malate is the specific metabolite that physically crosses the membrane via the dicarboxylate translocator, delivering reducing equivalents to support cytosolic processes.

246. (A) Coordination of sucrose and carbon fixation
Fructose-2,6-bisphosphate acts as a master regulator in the mesophyll cells of plants, coordinating the balance between carbon fixation and sucrose synthesis. By modulating the activity of key cytosolic enzymes, it ensures that the rate of sucrose production matches the availability of triose phosphates from the chloroplast. This control mechanism is vital for maintaining metabolic homeostasis and optimizing the.

247. (A) Inorganic Pyrophosphate (PPi)
The formation of ADP-glucose is a critical step in the biosynthesis of starch within plant plastids. The enzyme ADP-glucose pyrophosphorylase catalyzes the reaction between glucose-1-phosphate and ATP to produce the activated glycosyl donor. This specific reaction is accompanied by the release of inorganic pyrophosphate. The subsequent hydrolysis of pyrophosphate by inorganic pyrophosphatase helps to drive the overall.

248. (A) Plastid
In plant cells, the de novo synthesis of fatty acids is exclusively localized within the plastids, such as chloroplasts or proplastids. This process involves the sequential addition of two-carbon units to a growing chain, utilizing acetyl-CoA as the starting block. Once synthesized, these fatty acids are exported to the endoplasmic reticulum, where they are assembled into more.

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transfer of electrons to the primary acceptor, pheophytin, initiating the process of charge separation.

212. (A) DCMU (Diuron)
DCMU, also known as diuron, is a widely used herbicide that specifically targets the photosynthetic electron transport chain. It acts by binding to the Qb-binding site on the D1 protein of Photosystem II. This binding physically blocks the transfer of electrons from the tightly bound Qa to the loosely bound Qb, thereby halting the flow of electrons through the.

213. (C) 14
The CF0 portion of the chloroplast ATP synthase contains a rotary c-ring that is essential for proton translocation. In higher plants, this ring is typically composed of fourteen identical c-subunits. This specific structural stoichiometry dictates the number of protons that must pass through the complex to drive a full rotation and produce three molecules of ATP, establishing the.

214. (A) Dephosphorylating LHCII for grana migration
The transition from State 2 back to State 1 is a regulatory process that occurs when the plastoquinone pool becomes oxidized. This shift is mediated by the dephosphorylation of the Light-Harvesting Complex II. Once dephosphorylated, LHCII loses its affinity for Photosystem I and migrates back to the appressed regions of the grana to re-associate with Photosystem II, restoring.

215. (A) 1,3-BPG to glyceraldehyde-3-phosphate
During the reduction phase of the Calvin-Benson cycle, the plant utilizes the energy and reducing power generated by the light reactions. The specific step that requires NADPH is the conversion of 1,3-bisphosphoglycerate into glyceraldehyde-3-phosphate. This reaction is catalyzed by the enzyme glyceraldehyde-3-phosphate dehydrogenase and is essential for the formation of the triose phosphates used in sugar synthesis.

216. (A) L subunit in the chloroplast genome, S subunit in the nuclear genome
Rubisco is a complex enzyme whose synthesis requires the coordinated expression of genes from two different genomes. In higher plants, the large catalytic subunits are encoded by a single gene located within the chloroplast genome. In contrast, the small regulatory subunits are encoded by a family of genes in the nuclear genome and must be imported into the.

217. (A) Rubisco and FBPase have pH 8.0 optima
The light-induced alkalization of the chloroplast stroma is a fundamental regulatory mechanism for the Calvin cycle. Most enzymes in this pathway, particularly Rubisco and fructose-1,6-bisphosphatase, have alkaline pH optima around 8.0. By increasing the stromal pH from 7.0 to 8.0 upon illumination, the plant ensures that these enzymes are most active only when the light reactions are.

218. (A) Well-developed grana stacks
C4 plants of the NAD-malic enzyme subtype exhibit specific morphological characteristics that distinguish them from other C4 types. In these plants, the bundle sheath cells contain chloroplasts that possess well-developed grana stacks. This structural feature is associated with their unique biochemical pathway, where decarboxylation occurs primarily within the mitochondria, allowing the bundle sheath chloroplasts to maintain a high.

219. (A) Induce CAM, opening stomata at night
Facultative CAM plants possess the remarkable ability to switch their photosynthetic pathway in response to environmental conditions. Under well-watered conditions, they typically perform standard C3 photosynthesis. However, when subjected to severe drought or salinity stress, these plants induce the CAM pathway. This allows them to open their stomata at night to fix carbon dioxide while minimizing daytime water.

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220. (A) Detoxify hydrogen peroxide (H_2O_2) produced in the peroxisome
Catalase is an essential antioxidant enzyme located within the peroxisome of plant cells. Its primary function in the photorespiratory cycle is to detoxify the hydrogen peroxide that is produced by the oxidation of glycolate. By rapidly breaking down this reactive oxygen species into water and molecular oxygen, catalase protects the peroxisomal and cellular components from oxidative damage during.

and tubers. Because these organelles are not photosynthetic, they must import carbon from the cytosol. This is achieved by the transport of hexose phosphates, such as glucose-6-phosphate, or in some species, the activated precursor ADP-glucose, which are then.

183. (A) Blue region (approx 430 nm)
The absorption spectrum of chlorophyll is characterized by two principal peaks located in different regions of the visible spectrum. The peak in the blue region, occurring around 430 nanometers, is known as the Soret band. This high-energy absorption results from the excitation of electrons to a higher energy state. The other major peak is located in the.

184. (A) Maximize antenna complex density
The highly folded and stacked arrangement of thylakoid membranes within grana serves to optimize the light-harvesting capacity of the chloroplast. By maximizing the density of antenna complexes and Photosystem II reaction centers, this structure ensures the efficient capture of photons. Furthermore, the specialized environment within the grana stacks facilitates the rapid transfer of excitation energy and stabilizes the.

185. (A) Protochlorophyllide oxidoreductase
In angiosperms, the final steps of chlorophyll biosynthesis are strictly regulated by light. The enzyme protochlorophyllide oxidoreductase catalyzes the reduction of protochlorophyllide to chlorophyllide. This reaction is unique because the enzyme itself requires the absorption of light to initiate the hydride transfer from NADPH. This light-dependence ensures that chlorophyll is only produced when the seedling is exposed to solar.

186. (A) Fluorescence
When a pigment molecule absorbs a photon, it enters an excited state. If this energy is not used for photosynthesis or dissipated as heat, the molecule may return to its ground state by emitting a photon. This phenomenon is known as fluorescence. Because some energy is lost during the process, the emitted photon always has a longer wavelength.

187. (A) D1 protein
Tyrosine-Z is a specialized redox-active amino acid that plays an essential role in the water-splitting mechanism of Photosystem II. Structurally, this specific residue is located on the D1 protein, which forms part of the reaction center heterodimer. Tyrosine-Z acts as a rapid electron donor to the oxidized P680+ pigment, facilitating the transfer of electrons from the manganese cluster.

188. (A) Fa/Fb
Within the reaction center of Photosystem I, electrons are transferred through a series of internal carriers following excitation. The terminal electron acceptors in this chain are three specialized iron-sulfur centers. Specifically, the centers known as Fa and Fb are the final components within the protein complex. They receive electrons from the Fx center and subsequently pass them to ferredoxin.

189. (B) 4
During linear electron transport, the movement of electrons through the thylakoid membrane is coupled to the translocation of protons from the stroma to the lumen. For every pair of electrons transferred from water to $NADP^+$, a total of four protons are moved through the cytochrome b6f complex via the Q-cycle, in addition to those released during water oxidation.

190. (A) Antioxidant capacity and O_2 availability
Pseudocyclic electron transport, or the Mehler reaction, involves the transfer of electrons from Photosystem I to molecular oxygen. This process helps to maintain a proton gradient and generate ATP under conditions where NADP+ is limited. However, the continued operation of this pathway is constrained by the cell's antioxidant capacity to detoxify the resulting superoxide radicals and the.

191. (A) Open, Loose, and Tight states
The binding change mechanism, proposed by Paul Boyer, explains how the ATP synthase complex converts electrochemical energy into chemical bonds. Each of the three catalytic beta subunits exists in one of three distinct conformational states. The "Open" state has a low affinity for nucleotides, the "Loose" state binds ADP and phosphate, and the "Tight" state catalyzes the synthesis.

192. (A) Tightening of grana appression
Light-induced changes in the ion and proton concentrations of the chloroplast lead to

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230. (A) Cyanobacteria
Phycobilisomes are massive, water-soluble antenna complexes that are found in cyanobacteria and certain algal groups like red algae. They are physically attached to the stromal surface of the thylakoid membrane, where they efficiently capture light and transfer energy to the reaction centers. These complexes allow these organisms to thrive in environments with specific light qualities that are not.

231. (A) A dimer of chlorophyll a molecules
The primary electron donor in Photosystem II, known as P680, is a specialized pigment complex located within the reaction center. It is structurally composed of a dimer of chlorophyll a molecules. Upon the absorption of light energy, P680 reaches an excited state and releases an electron, initiating the process of charge separation and the subsequent flow of electrons.

232. (A) Phylloquinone (A1)
Within the reaction center of Photosystem I, the transfer of electrons follows a specific sequence of carriers. Following the primary charge separation, electrons move from the primary acceptor chlorophyll A0 to a specialized quinone molecule known as phylloquinone, or A1. This component then transfers the electrons to a series of iron-sulfur centers, continuing the journey toward the stromal.

233. (A) Cytochrome f
The cytochrome b6f complex contains several essential redox cofactors, including a unique c-type cytochrome known as cytochrome f. This high-potential protein is located on the lumenal side of the thylakoid membrane and plays a crucial role in the electron transport chain. It accepts electrons from the Rieske iron-sulfur protein and subsequently transfers them to the mobile carrier plastocyanin.

234. (A) Cytochrome c6
In some cyanobacteria and algae, environmental conditions can influence the choice of electron carriers. When copper availability is low, these organisms can produce cytochrome c6 as a functional replacement for the copper-containing protein plastocyanin. Cytochrome c6 is a soluble heme protein that efficiently shuttles electrons from the cytochrome b6f complex to Photosystem I, ensuring that photosynthesis can continue.

235. (A) The membrane must be selectively impermeable to protons
The generation of a proton motive force is a fundamental requirement for the synthesis of ATP in chloroplasts. For this force to be maintained, the thylakoid membrane must be selectively impermeable to protons. This property ensures that the pH gradient and electrical potential established by light-driven electron transport are not dissipated, allowing the energy to be used by.

236. (A) The reduction state of the plastoquinone pool/cytochrome b6f complex
Light-driven state transitions are regulated by a signaling cascade that responds to the redox status of the thylakoid membrane. The STN7 kinase is directly activated by the reduction of the plastoquinone pool and its subsequent interaction with the cytochrome b6f complex. This activation leads to the phosphorylation of LHCII, triggering its migration to Photosystem I and balancing.

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237. (A) Fructose-1,6-bisphosphate
In the Calvin-Benson cycle, the enzyme aldolase plays a key role in the formation of larger sugar phosphates during the regeneration phase. It catalyzes the reversible condensation of dihydroxyacetone phosphate with various aldose sugars. Specifically, it facilitates the formation of fructose-1,6-bisphosphate and sedoheptulose-1,7-bisphosphate. These reactions are essential for rearranging carbon skeletons to ultimately reconstruct the carbon dioxide acceptor molecule.

238. (A) ATP hydrolysis
Rubisco activase is a specialized molecular chaperone that is required to maintain the catalytic activity of Rubisco. The enzyme utilizes the energy derived from ATP hydrolysis to induce conformational changes in Rubisco. This mechanical action helps to remove tightly bound sugar phosphates that block the active site, ensuring that the enzyme remains in a state capable of fixing.

239. (A) Fructose-1,6-bisphosphatase (FBPase)
Fructose-1,6-bisphosphatase is a classic target of the ferredoxin-thioredoxin regulatory system within the chloroplast. This enzyme is responsible for the dephosphorylation of fructose-1,6-bisphosphate to produce fructose-6-phosphate. During the light, reduced thioredoxin activates the enzyme by modifying its disulfide bonds.

221. (A) The absolute lack of photorespiration
The theoretical maximum quantum yield of C3 photosynthesis represents the efficiency with which absorbed light is converted into fixed carbon. In an oxygen-free environment, the oxygenase activity of Rubisco is completely suppressed, effectively eliminating photorespiration. Under these ideal conditions, the quantum yield is at its highest and is dictated primarily by the stoichiometry of the Calvin cycle and.

222. (A) Fructose-6-phosphate (F6P)
The triose phosphate/phosphate translocator is a highly specific transport protein located in the inner chloroplast envelope. It primarily facilitates the exchange of triose phosphates, such as dihydroxyacetone phosphate and glyceraldehyde-3-phosphate, as well as 3-phosphoglycerate. However, it does not transport larger sugar phosphates like fructose-6-phosphate. The movement of these molecules is essential for coordinating carbon metabolism between the stroma.

223. (A) Imports 2-oxoglutarate for glutamate synthesis
The dicarboxylate translocator plays a vital role in nitrogen metabolism by facilitating the exchange of organic acids between the chloroplast and the cytosol. Its primary function in this context is to import 2-oxoglutarate into the chloroplast stroma. Once inside, 2-oxoglutarate serves as the necessary carbon skeleton for the synthesis of glutamate, which is then used for further amino.

224. (A) Hexose phosphates (e.g., G6P) or ADP-glucose
The synthesis of starch in non-photosynthetic sink tissues requires a steady supply of carbon from the cytosol to the amyloplasts. In most plants, this is achieved by importing hexose phosphates, such as glucose-6-phosphate, or in some specific cases, the activated precursor ADP-glucose. These molecules are then used as the substrates for starch synthase and other enzymes to.

225. (A) Granule-Bound Starch Synthase (GBSS)
Amylose is the linear component of starch and its biosynthesis is catalyzed by a specialized enzyme. Granule-bound starch synthase is uniquely responsible for this final committed step. Unlike soluble starch synthases that produce amylopectin, GBSS is physically integrated into the starch granule and elongates the glucan chains to form amylose. This enzyme is essential for determining the overall structure.

226. (A) A phospholipid monolayer embedded with oleosins
Oleosomes, also known as lipid bodies, are specialized organelles for storing triacylglycerols in seeds. Unlike typical organelles surrounded by a phospholipid bilayer, oleosomes are bounded by a unique phospholipid monolayer. This monolayer is embedded with specialized structural proteins called oleosins. This specific organization stabilizes the hydrophobic lipid core and prevents the droplets from coalescing during seed dehydration and subsequent.

227. (A) Plot of response magnitude vs wavelength
An action spectrum and an absorption spectrum provide different types of information about a biological process. An absorption spectrum measures the physical amount of light absorbed by a pigment across different wavelengths. In contrast, an action spectrum plots the magnitude of a specific physiological response, such as the rate of photosynthesis, as a function of the wavelength of.

228. (A) Cation-mediated electrostatic interactions between adjacent thylakoid surfaces
The highly organized structure of grana stacks within the chloroplast is maintained by specific molecular forces. The stability of these stacks relies largely on cation-mediated electrostatic interactions between the adjacent surfaces of thylakoid membranes. Additionally, the presence of Light-Harvesting Complex II and other structural proteins helps to mediate the adhesion between membranes, ensuring the integrity of the light-harvesting.

229. (A) Reduction of protochlorophyllide to chlorophyllide
In higher plants, the conversion of protochlorophyllide to chlorophyllide is a critical step in the chlorophyll biosynthetic pathway that is strictly light-dependent. This reaction is catalyzed by the enzyme protochlorophyllide oxidoreductase, which requires the absorption of light to drive the reduction process. This mechanism ensures that seedlings do not accumulate large amounts of chlorophyll until they are exposed to.

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249. (A) Simultaneous red and far-red synergistic rate
The Emerson enhancement effect describes the synergistic increase in the rate of photosynthesis observed when plants are simultaneously exposed to red and far-red light. This effect occurs because the two wavelengths preferentially excite different photosystems. By providing both types of light, the plant can balance the activity of Photosystem II and Photosystem I, maximizing the efficiency of the.

250. (A) A cylindrical stack of flattened thylakoid discs
A granum is a highly organized structural unit within the chloroplast, consisting of a cylindrical stack of flattened, disc-shaped thylakoid membranes. These stacked regions are characterized by a high density of Photosystem II and its associated antenna complexes. The specific arrangement of grana, connected by unstacked stroma lamellae, creates a complex internal architecture that optimizes the capture and.

251. (A) Extensive system of conjugated double bonds
Carotenoids are characterized by an extensive system of conjugated double bonds along their long polyene chains. This unique chemical feature allows these pigments to effectively absorb light in the blue and green regions of the spectrum. Furthermore, the electronic structure of these bonds enables carotenoids to quench triplet chlorophyll and singlet oxygen, providing essential photoprotection by dissipating excess energy.

252. (A) Pigments are held in optimized orientations
The transfer of excitation energy within antenna pigment-protein complexes is exceptionally efficient because the pigments are held in highly optimized orientations and distances by the protein scaffold. This precise organization ensures that the energy is funneled toward the reaction center with minimal loss to other non-radiative processes. This structural arrangement is fundamental to the overall efficiency of photosynthetic energy.

253. (A) Lumenal localization in thylakoid membrane
The oxygen-evolving complex is located on the lumenal side of the thylakoid membrane, which provides a specialized environment for the water-splitting reaction. This internal localization serves to protect the rest of the chloroplast from the harmful reactive intermediates produced during the process. By sequestering these species within the lumen, the plant ensures that the highly oxidizing.

254. (A) PsaC
Within the multi-protein complex of Photosystem I, the transfer of electrons to the stroma involves several specialized iron-sulfur centers. The centers known as Fa and Fb are the final electron acceptors within the reaction center core. These two clusters are specifically bound to the PsaC protein subunit, which is located on the stromal surface of the complex.

255. (A) Exergonic irreversible cytochrome steps
In the linear electron transport chain, the unidirectional flow of electrons from Photosystem II to Photosystem I is maintained by several exergonic and essentially irreversible steps. Specifically, the transfer of electrons through the cytochrome b6f complex and the subsequent reduction of plastocyanin involve significant drops in free energy. These thermodynamically favorable reactions prevent electrons from flowing backward, ensuring.

256. (A) PGR5/PGRL1 or NDH complex pathway
Cyclic electron transport relies on pathways that redirect electrons from ferredoxin back into the plastoquinone pool. In higher plants, this process is primarily mediated by either the PGR5/PGRL1 protein complex or the NDH complex. By recycling electrons through the cytochrome b6f complex, these pathways generate a proton gradient for ATP synthesis without the simultaneous production of NADPH.

257. (A) Subunit count in the rotor ring
The stoichiometry of ATP synthesis, which relates the number of protons translocated to the number of ATP molecules produced, is fundamentally determined by the structure of the ATP synthase rotor. Specifically, the number of c-subunits in the rotor ring dictates how many protons are required for one full rotation of the enzyme, which typically yields three ATP molecules.

258. (A) 5.5 - 6.5
During active photosynthesis, the light-driven pumping of protons into the thylakoid lumen creates a significant pH gradient across the membrane. Under steady-state illumination,

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is concentrated in the stacked grana, while Photosystem I is located in the unstacked stroma lamellae, ensuring they function as.

297. (A) Calcium (Ca^{2+})
The structural and functional integrity of the oxygen-evolving complex requires the presence of several essential inorganic cofactors. In addition to the four manganese ions that form the catalytic cluster, the complex strictly requires one calcium ion. Calcium is necessary for stabilizing the water-splitting center and facilitating the efficient transfer of electrons from water molecules to the reaction.

298. (A) A0 is Chl, A1 is quinone, others are clusters
Within the core of Photosystem I, electrons move through a sequence of carriers that have distinct chemical natures. The primary acceptor, A0, is a specialized chlorophyll monomer, and the secondary acceptor, A1, is a phylloquinone molecule. The subsequent carriers in the chain, designated as Fx, Fa, and Fb, are all specialized iron-sulfur clusters that facilitate electron.

299. (A) The Rieske iron-sulfur protein and cytochrome f
The cytochrome b6f complex is a central component of the electron transport chain, facilitating the movement of electrons between the two photosystems. In the high-potential chain, the complex transfers an electron from the Rieske iron-sulfur protein to cytochrome f. Finally, cytochrome f donates the electron to the mobile carrier plastocyanin, which then shuttles it to Photosystem.

300. (A) High light intensity and low CO_2 availability
The water-water cycle, also known as pseudocyclic electron flow, plays a significant physiological role under environmental conditions of high light intensity and limited carbon dioxide availability. When the Calvin cycle is unable to utilize all the generated reducing power, this pathway allows the plant to safely dissipate excess energy. It generates a proton gradient for ATP synthesis.

****

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Additionally, the organic acids involved in the shuttle serve as.

268. (A) Light and high glucose-6-phosphate
Sucrose-phosphate synthase is a key regulatory enzyme in the biosynthesis of sucrose. Its activity is modulated by reversible phosphorylation and allosteric factors. In leaves, the enzyme is activated in the light through dephosphorylation and the accumulation of glucose-6-phosphate. These conditions signal that the plant has sufficient carbon and energy for sucrose production, ensuring that synthesis is synchronized.

269. (A) A total inability to synthesize leaf starch
A mutant plant that lacks the enzyme ADP-glucose pyrophosphorylase would be unable to synthesize ADP-glucose, the essential precursor for starch. Consequently, such a plant would exhibit a total inability to produce leaf starch. While it can still perform photosynthesis and synthesize sucrose, the lack of starch reserves would affect its ability to maintain growth and metabolism.

270. (A) Diacylglycerol acyltransferase (DGAT)
The final step in the synthesis of triacylglycerols in developing seeds involves the acylation of diacylglycerol. This critical reaction is catalyzed by the enzyme diacylglycerol acyltransferase. By adding a third fatty acid to the glycerol backbone, DGAT completes the formation of the storage lipid. This enzyme is a major control point for the accumulation of oil.

271. (B) 8 to 10
The quantum requirement of photosynthesis is defined as the number of photons needed to fix one molecule of carbon dioxide. In a typical C3 plant under normal atmospheric conditions, this requirement is generally between 8 and 10 photons. This value reflects the stoichiometry of the light reactions and the Calvin cycle, while accounting for the energy lost during.

272. (A) The tightly stacked membrane areas within grana
The thylakoid membrane system is organized into stacked and unstacked regions. Appressed regions are the tightly stacked areas within the grana where adjacent membrane surfaces are in direct contact. These regions are characterized by a high concentration of Photosystem II and its light-harvesting antenna complexes. This dense organization facilitates efficient energy capture and transfer within the grana.

273. (A) Methylerythritol phosphate (MEP) pathway
The long, hydrophobic phytol tail of the chlorophyll molecule is synthesized through the methylerythritol phosphate pathway. This pathway, located within the plastid, provides the isoprenoid precursors necessary for the synthesis of phytol and various other terpenoid compounds, such as carotenoids and tocopherols. The integration of the phytol chain into the porphyrin ring is the final step.

274. (A) Picoseconds to nanoseconds
The transfer of excitation energy from antenna pigments to the reaction center is a remarkably rapid process. Due to the precise orientation and proximity of the pigment molecules, energy migration occurs within a timeframe of picoseconds to nanoseconds. This speed is essential for maximizing the efficiency of light harvesting and minimizing the loss of energy to other non-productive.

275. (A) CP43 and CP47
Within the core of Photosystem II, several protein subunits are responsible for binding the internal antenna chlorophylls. Specifically, the CP43 and CP47 proteins bind approximately 30 to 40 chlorophyll a molecules. These internal antennas serve to collect energy from the outer Light-Harvesting Complex II and funnel it toward the P680 reaction center, playing a vital role.

276. (A) -1.0 V
Photosystem I is characterized by its ability to generate an extremely strong reductant. The primary electron acceptor, A0, which is a specialized chlorophyll a monomer, has a very negative midpoint redox potential of approximately -1.0 volts. This potential provides the necessary thermodynamic drive to transfer electrons through a series of iron-sulfur centers to eventually reduce ferredoxin.

277. (B) 2
The oxidation of one molecule of plastoquinol at the cytochrome b6f complex is coupled to the movement of protons across the membrane. Through the operation of the Q-cycle, each PQH2 molecule that is oxidized results in the net translocation of two protons from the stroma

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power than assimilating ammonia.
(B) Ammonia assimilation relies purely on passive diffusion without ATP.
(C) Nitrate assimilation produces a net surplus of ATP.
(D) Both ammonia and nitrate assimilation are strictly exergonic processes.

2018

30. Consider the following statements about nutrient assimilation:
I. Nitrogen assimilation strictly occurs in root tissues.
II. Light enhances nitrate reduction in leaves by providing ferredoxin.
III. Glutamine is a major transport form of assimilated nitrogen.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2006

31. Under severe phosphorus starvation, plants typically bypass ATP-dependent glycolysis steps using alternative enzymes. Which enzyme is a hallmark of this bypass?
(A) Hexokinase
(B) Pyrophosphate-dependent phosphofructokinase (PFP)
(C) Phosphofructokinase
(D) Pyruvate kinase

2019

32. Which heavy metal is specifically required for the assimilation of urea into ammonia in plants?
(A) Cobalt
(B) Copper
(C) Nickel
(D) Manganese

2009

33. The formation of phytochelatins is a critical response to heavy metal toxicity. Which nutrient is directly required for their biosynthesis?
(A) Sulfur
(B) Phosphorus
(C) Calcium
(D) Iron

2004

34. What physiological disorder arises specifically due to impaired calcium assimilation causing localized cell death in growing tissues?
(A) Little leaf disease in zinc deficiency
(B) White bud in maize
(C) Khaira disease of rice
(D) Blossom end rot in tomatoes

2005

35. Identify the INCORRECT statement concerning iron assimilation and deficiency.
(A) Iron deficiency typically causes interveinal chlorosis in young leaves.
(B) Iron assimilation strictly occurs in the dark.
(C) Chelates are often used to correct iron deficiency in soils.
(D) Iron is a key component of cytochromes in the electron transport chain.

2021

36. Which process links mineral nutrient assimilation directly to the pentose phosphate pathway?
(A) Generation of ATP via oxidative phosphorylation
(B) Production of ribulose-1,5-bisphosphate
(C) Synthesis of lignin monomers
(D) Provision of NADPH for reductive assimilation steps

2005

37. In which primary cellular compartment does the reduction of sulfate to sulfide occur in higher plants?
(A) Plastids
(B) Mitochondria
(C) Vacuole
(D) Cytosol

2002

38. The activation of sulfate prior to its reduction requires ATP. Which enzyme catalyzes this initial activation step?
(A) APS reductase
(B) Sulfite reductase
(C) ATP sulfurylase
(D) O-acetylserine (thiol) lyase

2012

39. What is the immediate product formed by the action of ATP sulfurylase on sulfate?
(A) Adenosine 5'-phosphosulfate (APS)
(B) 3'-phosphoadenosine 5'-phosphosulfate (PAPS)
(C) Sulfite
(D) Cysteine

2025

40. Consider the following statements regarding the sulfate reduction pathway:
I. APS is directly reduced to sulfite by APS

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due to their specialized carbon-concentrating mechanism. This system effectively saturates the Rubisco enzyme with carbon dioxide within the bundle sheath cells, virtually eliminating the oxygenase activity and the subsequent wasteful photorespiration. This allows the plants to maintain high productivity even under conditions that would otherwise.

288. (A) Immediate cessation of electron transport to plastoquinone
Under conditions of excessive light intensity, the D1 protein of Photosystem II is highly susceptible to photo-oxidative damage. The most immediate consequence of this damage is the cessation of electron transport from the reaction center to the plastoquinone pool. This leads to the inactivation of the photosystem and requires a specialized repair cycle to replace the damaged.

289. (A) NADP-malate dehydrogenase (NADP-MDH)
The malate-oxaloacetate shuttle is a vital mechanism for exporting reducing power from the chloroplast stroma. Within this system, the enzyme NADP-malate dehydrogenase is responsible for the direct conversion of oxaloacetate into malate using NADPH. This reaction occurs in the stroma and produces the malate that is subsequently exported via the dicarboxylate translocator to deliver reducing.

290. (A) Abundant sink demand and promote sucrose export while inhibiting starch synthesis
The partitioning of carbon between starch and sucrose is strictly coordinated by the concentration of inorganic phosphate in the cytosol. High levels of cytosolic phosphate signal that there is abundant sink demand for sucrose. This promotes the export of triose phosphates from the chloroplast and inhibits the synthesis of starch, ensuring that carbon is effectively utilized for.

291. (A) Starch phosphorylase
The degradation of transient starch in chloroplasts involves several enzymes working in parallel. While amylases are responsible for hydrolytic cleavage, starch phosphorylase plays a major role in the phosphorolytic cleavage of the glucan chains. This enzyme uses inorganic phosphate to release glucose-1-phosphate from the non-reducing ends of the starch polymer, providing a direct route for carbon.

292. (A) Globulins
Legume seeds, such as soybean and pea, are characterized by their high protein content. The predominant class of storage proteins in these seeds are globulins, which are typically classified into two major groups: vicilins and legumins. These proteins are synthesized on the rough endoplasmic reticulum and accumulated within protein storage vacuoles to provide a nitrogen source for.

293. (A) The quantum efficiency of Photosystem II
Chlorophyll fluorescence is a powerful non-invasive diagnostic tool used in plant physiology to assess the health and efficiency of the photosynthetic apparatus. It provides detailed information about the quantum efficiency of Photosystem II and the rate of electron transport. By measuring how a leaf dissipates absorbed light energy, researchers can detect stress and evaluate the overall.

294. (A) Fatty acid desaturase
The fluidity of the thylakoid membrane is critical for the proper functioning of photosynthetic complexes and is maintained by a high concentration of unsaturated lipids. Enzymes known as fatty acid desaturases are responsible for introducing double bonds into the fatty acid chains of membrane lipids. This process is essential for adapting to changes in temperature and ensuring the.

295. (A) Anthocyanins
Anthocyanins are a class of water-soluble pigments that are stored within the central vacuole of plant cells. Unlike chlorophylls and carotenoids, they are not directly involved in the light-harvesting reactions of photosynthesis. Instead, they provide various colors to flowers and fruits and serve important roles in protecting tissues from ultraviolet radiation and attracting pollinators and seed.

296. (A) Segregation in grana vs stroma regions
Uncontrolled energy transfer, or spillover, from Photosystem II to Photosystem I would reduce the overall efficiency of photosynthesis. The chloroplast prevents this by spatially segregating the two photosystems within different regions of the thylakoid membrane. Photosystem II

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the pH of the lumen typically drops to a range between 5.5 and 6.5. This acidification is essential for the activation of certain photoprotective mechanisms, such as non-photochemical quenching, and provides the necessary.

259. (A) It uses ATP to phosphorylate ribulose-5-phosphate, regenerating RuBP
Phosphoribulokinase is a critical enzyme in the regeneration phase of the Calvin-Benson cycle. It catalyzes the phosphorylation of ribulose-5-phosphate using ATP to regenerate the primary carbon dioxide acceptor, ribulose-1,5-bisphosphate. This reaction is a key control point and is regulated by the ferredoxin-thioredoxin system to ensure that RuBP is produced only when light energy is available to.

260. (A) Identical binding sites for oxygen and carbon dioxide
The catalytic promiscuity of Rubisco, where it reacts with both carbon dioxide and molecular oxygen, is a consequence of the identical binding sites for these two gases. Because the enzyme must bind the enediolate intermediate to react with CO_2, it inevitably becomes susceptible to attack by O_2. This inherent chemical limitation is an evolutionary consequence that dictates the baseline rate.

261. (A) An iron-sulfur center coupled with redox-active disulfides
Ferredoxin-thioredoxin reductase is a specialized enzyme that links the light reactions to metabolic control. It contains a unique iron-sulfur center coupled with redox-active disulfide bonds. This arrangement allows FTR to perform a two-electron reduction of thioredoxin using single electrons from ferredoxin. This specific chemical mechanism is essential for translating the light signal into changes in the.

262. (A) Diminished or completely lack grana
In some C4 grass species, the bundle sheath chloroplasts exhibit a specialized structural adaptation known as agranality. These chloroplasts have greatly diminished or completely lack grana stacks, consisting primarily of unstacked stroma lamellae. This structural modification is often associated with a reduction in Photosystem II activity, which helps to maintain high internal concentrations of carbon dioxide by.

263. (A) Clock kinase and light-driven efflux
The shift from nocturnal carbon fixation to daytime decarboxylation in CAM plants is governed by a complex regulatory system. A specific clock-controlled kinase modulates the activity of PEP carboxylase through reversible phosphorylation. Additionally, the light-induced changes in the cell, such as the efflux of malate from the vacuole, signal the transition to Phase III of the pathway.

264. (A) Yield one 3-PGA and one CO_2 via C_2 cycle
Rubisco oxygenase activity produces 2-phosphoglycolate, which must be processed to recover carbon. The two molecules of 2-phosphoglycolate are recycled through the photorespiratory C_2 cycle, which involves reactions in the chloroplast, peroxisome, and mitochondrion. The net result of this scavenger pathway is the production of one molecule of 3-phosphoglycerate and the release of one molecule of carbon.

265. (A) CAM > C_4 > C_3
The major photosynthetic pathways exhibit different levels of water-use efficiency based on their specific adaptations. CAM plants are the most efficient because they fix carbon at night when transpiration is minimal. C_4 plants are more efficient than C_3 plants due to their carbon-concentrating mechanism, which allows them to fix carbon even with partially closed stomata. Therefore, the.

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266. (A) Export triose phosphates for Pi
In a mature source leaf, the primary role of the triose phosphate/phosphate translocator is to facilitate the export of photosynthetic products. As triose phosphates are produced in the stroma, the TPT exports them to the cytosol in exchange for inorganic phosphate. This exported carbon is then used for the synthesis of sucrose, which is subsequently loaded.

267. (A) Assimilation of newly reduced nitrogen into amino acids
The malate-oxaloacetate shuttle is essential for coordinating redox states between different cellular compartments. Beyond its role in energy transfer, the shuttle also provides critical support for nitrogen assimilation. By exporting reducing equivalents to the cytosol, it ensures a steady supply of power for nitrate reduction.

CHAPTER 08
Plant Metabolic Processes

2023

1. Which criterion is essential for an element to be classified as an essential plant nutrient?
(A) The plant cannot complete its life cycle in its absence.
(B) The element must be present in all species in high amounts.
(C) The element can be replaced by another similar element.
(D) The element must primarily enhance resistance to stress.

2001

2. Which of the following elements is classified as a micronutrient but is essential for the activation of numerous enzymes and proper structural integrity of ribosomes?
(A) Calcium
(B) Copper
(C) Zinc
(D) Phosphorus

2003

3. What is the primary role of molybdenum in plant nutrition?
(A) Cofactor for nitrate reductase and nitrogenase.
(B) Structural component of the chlorophyll molecule.
(C) Key constituent used in forming plant cell walls.
(D) Primary osmoregulator found in leaf guard cells.

2002

4. Identify the INCORRECT statement regarding plant macronutrients.
(A) Potassium is crucial for maintaining turgor pressure.
(B) Phosphorus is a vital component of nucleic acids and phospholipids.
(C) Sulfur is an essential component of cysteine and methionine.
(D) Iron is required in large quantities as a central atom of chlorophyll.

2017

5. The deficiency of which essential nutrient typically leads to interveinal chlorosis in older leaves first, due to its high mobility within the plant?
(A) Iron
(B) Magnesium
(C) Calcium
(D) Boron

2017

6. Which nutrient deficiency is uniquely characterized by "whiptail" disease in brassicas?
(A) Copper
(B) Manganese
(C) Molybdenum
(D) Zinc

2021

7. Which pair belongs to the group of nutrients that form structural organic molecules based on biochemical function?
(A) Potassium and Calcium
(B) Boron and Chlorine
(C) Copper and Iron
(D) Nitrogen and Sulfur

2018

8. Nickel was recognized as an essential plant nutrient relatively recently. What is its specific known function in plant metabolism?
(A) Structural component of the enzyme urease
(B) Cofactor for plastocyanin in photosynthesis
(C) Activator of starch branching enzyme
(D) Core atom in vitamin B12 synthesis

2014

9. In the context of essential nutrient mobility, which of the following elements is generally considered highly immobile, causing deficiency symptoms to appear first in young leaves?
(A) Nitrogen
(B) Calcium
(C) Phosphorus
(D) Magnesium

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into the thylakoid lumen. Therefore, for every pair of electrons transferred.

278. (A) Dissipates excess while yielding ATP
Pseudocyclic photophosphorylation, also known as the Mehler reaction or the water-water cycle, serves as a vital photoprotective "safety valve." Under conditions where light energy exceeds the plant's capacity for carbon fixation, this pathway dissipates excess excitation energy by transferring electrons to molecular oxygen. This process generates ATP while preventing the over-reduction of the electron transport chain.

279. (A) ATPase activity (hydrolysis of ATP)
The CF1 unit of the chloroplast ATP synthase is the catalytic portion that projects into the stroma. If it is physically separated from the membrane-bound CF0 portion, it loses its ability to synthesize ATP. Instead, the isolated CF1 particle primarily demonstrates ATPase activity, meaning it catalyzes the hydrolysis of ATP into ADP and inorganic phosphate in.

280. (A) LHCII lateral mobility and phosphorylation
State transitions are a key regulatory mechanism for balancing energy between the two photosystems. This process relies heavily on the lateral mobility of the Light-Harvesting Complex II within the thylakoid membrane. When LHCII is phosphorylated, its migration between the stacked grana and the unstacked stroma lamellae alters the architecture of the grana and redistributes excitation energy toward.

281. (A) Reduction of 3-phosphoglycerate to glyceraldehyde-3-phosphate
The reduction phase of the Calvin-Benson cycle is the most energy-intensive stage of carbon assimilation. Specifically, the conversion of 3-phosphoglycerate into glyceraldehyde-3-phosphate requires two distinct steps. First, the molecule is phosphorylated using ATP to form 1,3-bisphosphoglycerate. Subsequently, this intermediate is reduced by NADPH. Therefore, this transformation is the only reaction in the cycle that directly.

282. (A) 2-Carboxyarabinitol-1-phosphate (CA1P)
In the dark, the activity of Rubisco is often suppressed by the binding of a naturally occurring inhibitor called 2-carboxyarabinitol-1-phosphate. CA1P binds tightly to the uncarbamylated active site of the enzyme, preventing its activation. Upon illumination, Rubisco activase facilitates the removal of this inhibitor, allowing the enzyme to undergo carbamylation and return to its catalytically active state.

NODIA

283. (A) Conformational changes that expose or shape the active site for catalysis
The ferredoxin-thioredoxin system regulates Calvin cycle enzymes through reversible redox changes. When reduced thioredoxin interacts with its target enzymes, it reduces their critical disulfide bonds to sulfhydryl groups. This specific chemical modification induces conformational changes that either expose the active site or reshape its structure to enhance catalytic efficiency. This mechanism ensures that carbon fixation is synchronized with.

284. (A) Phosphoenolpyruvate
In C4 plants of the phosphoenolpyruvate carboxykinase subtype, the decarboxylation process in the bundle sheath cells is unique. The enzyme PEPCK catalyzes the conversion of oxaloacetate into phosphoenolpyruvate and carbon dioxide. This reaction requires ATP and uniquely yields PEP as the byproduct, which then returns to the mesophyll cells to be utilized in the initial carboxylation.

285. (A) Stomatal opening in the late afternoon allowing direct C3 photosynthesis
Phase IV of Crassulacean Acid Metabolism occurs in the late afternoon when the vacuolar malate reserves are nearly depleted. During this stage, the stomata may partially open, allowing for a period of direct C3-like photosynthesis. This phase represents a transition back to nocturnal fixation and allows the plant to maximize carbon gain when external conditions are more favorable.

286. (A) Consumption of energy and 0.5 CO_2 loss
When Rubisco reacts with molecular oxygen instead of carbon dioxide, it initiates the photorespiratory cycle. For every molecule of oxygen consumed, the scavenger pathway ultimately recovers seventy-five percent of the carbon. However, this process comes at a cost, as it results in the net loss of 0.5 molecules of carbon dioxide and the significant consumption of metabolic.

287. (A) C4 pump saturates Rubisco with CO_2
C4 crop plants generally exhibit higher maximum rates of photosynthesis than C3 plants

(D) By completely repressing the expression of iron-regulated transporters

2017

20. Match the ion transport mechanism in List I with its defining characteristic in List II.

List I : (Mechanism)

P. Uniport
Q. Symport
R. Antiport
S. Aquaporin

List II : (Characteristic)

1. Movement of two substances in the same direction
2. Passive transport of water molecules
3. Facilitated diffusion of a single species
4. Movement of two substances in opposite directions

(A) P-I, Q-IV, R-II, S-III
(B) P-III, Q-II, R-IV, S-I
(C) P-II, Q-III, R-I, S-IV
(D) P-III, Q-I, R-IV, S-II

2001

21. Which statement best describes the "apparent free space" in root ion uptake?
(A) The volume of the vacuole where ions are stored.
(B) The root cortex apoplast accessible via diffusion.
(C) The symplastic continuum through plasmodesmata.
(D) The internal lumen of the conducting xylem vessels.

2005

22. In the dual isotherm model of ion uptake, what does Mechanism II at high external concentrations represent?
(A) High-affinity, low-capacity transporters
(B) Purely passive diffusion without any protein involvement
(C) Low-affinity, high-capacity transport systems
(D) Vesicular exocytosis of accumulated ions

2022

23. What role does the Casparian strip play in mineral ion uptake?
(A) It blocks apoplastic movement of water and ions.
(B) It actively pumps toxic ions out of the endodermis.
(C) It facilitates rapid symplastic transport to cortex.
(D) It synthesizes carrier proteins for active transport.

2002

24. Which condition most profoundly inhibits active ion uptake in roots?
(A) Enhanced root respiration
(B) Abundant supply of ATP
(C) Optimal soil temperature
(D) Hypoxia or treatment with respiratory inhibitors

2025

25. Once assimilated, how is excess toxic ammonia rapidly detoxified within plant cells?
(A) Conversion into nitrate via nitrate reductase
(B) Excretion directly through stomata
(C) Incorporation into glutamate to form glutamine
(D) Condensation into uric acid crystals

2002

26. Which metabolic deficiency symptom is correctly paired with the responsible nutrient assimilation pathway disruption?
(A) Magnesium deficiency – Impaired nitrogenase activity
(B) Phosphorus deficiency – Inhibition of carbon fixation
(C) Sulfur deficiency – Reduced synthesis of amino acids
(D) Zinc deficiency – Blocked cellular starch degradation

2023

27. What is the primary initial product of nitrogen assimilation via the GS-GOGAT cycle?
(A) Glutamate
(B) Asparagine
(C) Urea
(D) Arginine

2010

28. Identify the correct enzyme pair crucial for primary ammonia assimilation in plants.
(A) Glutamine synthetase and Glutamate synthase
(B) Glutamate dehydrogenase and Nitrate reductase
(C) Aspartate aminotransferase and Urease
(D) Nitrogenase and Nitrite reductase

2003

29. Which statement accurately describes the energetic cost of nitrogen assimilation?
(A) Assimilating nitrate requires more reducing

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2018

10. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Silicon is considered an essential element for all higher plants.
Reason (R) : Silicon strengthens cell walls and improves pest resistance in grasses.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2016

11. Which element serves as a critical structural element in the middle lamella, bridging pectic chains?
(A) Calcium
(B) Potassium
(C) Boron
(D) Manganese

2002

12. Which of the following nutrients is most directly associated with pollen germination and tube growth?
(A) Iron
(B) Copper
(C) Boron
(D) Chlorine

2010

13. Which process characterizes the active transport of mineral ions across a plant cell membrane?
(A) Movement strictly down a concentration gradient.
(B) Free diffusion through the lipid bilayer regions.
(C) Water-driven solvent drag through plasmodesmata.
(D) Movement against a gradient using ATP hydrolysis.

2023

14. What distinguishes a primary active transport mechanism from a secondary active transport mechanism in roots?
(A) Primary transport moves water, whereas secondary transport moves solutes.
(B) Secondary active transport is independent of membrane proteins.
(C) Primary uses ATP directly, while secondary uses electrochemical gradients.
(D) Primary active transport only occurs in the xylem.

2002

15. The concept of carrier-mediated ion uptake is analogous to enzyme kinetics. Which phenomenon provides strong evidence for this concept?
(A) Linear uptake rate regardless of external ion concentration
(B) Saturation kinetics at high external ion concentrations
(C) Independent uptake of structurally identical ions
(D) Complete absence of competitive inhibition

2017

16. Identify the INCORRECT statement regarding ion channels in plant membranes.
(A) They are integral membrane proteins that form hydrophilic pores.
(B) They can be gated by voltage, specific ligands, or mechanical stress.
(C) They allow rapid, passive movement of ions down electrochemical gradients.
(D) They transport ions exclusively via active transport against gradients.

NODIA

2007

17. The plasma membrane H+-ATPase plays a central role in nutrient uptake. What is its primary function?
(A) Extruding protons to the apoplast to establish an electrochemical gradient
(B) Pumping protons into the cytoplasm to raise cellular pH
(C) Synthesizing ATP using a proton gradient
(D) Facilitating the symport of protons and cations out of the cell

2021

18. Which specific transporter class facilitates the movement of anions like nitrate into the root cell against their electrical gradient?
(A) Proton-anion antiporters
(B) Anion uniports
(C) Proton-anion symporters
(D) Voltage-gated anion channels

2003

19. How do plants typically adapt to acquire iron from calcareous soils where iron solubility is extremely low?
(A) By secreting phytosiderophores to chelate Fe^{3+} (Strategy II)
(B) By releasing massive amounts of hydroxyl ions
(C) By increasing internal pH to solubilize iron

reductase.
II. Sulfite is reduced to sulfide by a ferredoxin-dependent sulfite reductase.
III. The process predominantly occurs in root vacuoles.
IV. Cysteine is the first stable organic product of sulfur assimilation.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, II and III
(C) II, III and IV
(D) I and IV

2024

41. What is the role of O-acetylserine in sulfur metabolism?
(A) It provides the carbon skeleton for the incorporation of sulfide to form cysteine.
(B) It acts as a signaling molecule to suppress sulfate uptake.
(C) It is the oxidized form of methionine.
(D) It functions as a competitive inhibitor of ATP sulfurylase.

2023

42. Which enzyme complex strictly catalyzes the final step of cysteine biosynthesis?
(A) Cystathionine gamma-synthase and Cystathionine beta-lyase
(B) Homocysteine methyltransferase
(C) Serine acetyltransferase and O-acetylserine(thiol)lyase
(D) S-adenosylmethionine synthetase

2016

43. From which precursor amino acid is the carbon skeleton of methionine ultimately derived?
(A) Aspartate
(B) Glutamate
(C) Glycine
(D) Alanine

2017

44. What intermediate links the biosynthetic pathways of cysteine and methionine?
(A) Homocysteine
(B) S-adenosylmethionine (SAM)
(C) Glutathione
(D) Cystathionine

2008

45. Which regulatory mechanism most accurately describes the control of the sulfate assimilation pathway?
(A) Upregulation by high internal cysteine and glutathione concentrations
(B) Complete independence from nitrogen assimilation status
(C) Feedback inhibition of ATP sulfurylase by accumulated thiols
(D) Irreversible inhibition of APS reductase by light

2023

46. Besides structural roles in proteins, what is a critical physiological function of the sulfur-containing tripeptide glutathione?
(A) Serving as the primary long-distance transport form of nitrogen
(B) Acting as a major cellular antioxidant and redox buffer
(C) Functioning as a structural unit of the cell wall
(D) Catalyzing the fixation of atmospheric carbon dioxide

2002

47. Which secondary plant metabolites are characterized by an S-containing glucoside structure and act as a defense mechanism primarily in the Brassicaceae family?
(A) Cyanogenic glycosides
(B) Alkaloids
(C) Phytoalexins
(D) Glucosinolates

2006

48. Identify the main transport form of sulfur from leaves to sinks via the phloem.
(A) Glutathione and S-methylmethionine
(B) Free sulfate ions
(C) Hydrogen sulfide gas
(D) Adenosine 5'-phosphosulfate

2015

49. In the global nitrogen cycle, which biochemical process is defined as the conversion of organic nitrogenous compounds into ammonia?
(A) Denitrification
(B) Ammonification
(C) Nitrification
(D) Nitrogen fixation

2023

50. Consider the following statements about denitrification:
I. It is an anaerobic respiratory process.
II. It converts nitrate strictly back to ammonia.
III. Pseudomonas and Bacillus species are common denitrifiers.
IV. It results in a net loss of biologically available nitrogen from the soil.

NODIA

V. It utilizes nitrate as a terminal electron acceptor.

Which of the above statement(s) is/are correct?
(A) I, II, III and V
(B) I, III, IV and V
(C) II, III, IV and V
(D) I, IV and V

2006

51. The oxidation of ammonia to nitrite in the soil is primarily catalyzed by which group of organisms?
(A) Nitrobacter species
(B) Nitrosomonas species
(C) Rhizobium species
(D) Azotobacter species

2004

52. Which enzyme complex in nitrifying bacteria initiates the oxidation of ammonia?
(A) Hydroxylamine oxidoreductase
(B) Nitrite oxidoreductase
(C) Nitrate reductase
(D) Ammonia monooxygenase

2006

53. Identify the intermediate compound formed during the oxidation of ammonia to nitrite.
(A) Nitric oxide
(B) Hydroxylamine
(C) Hydrazine
(D) Nitrous oxide

2022

54. What is the specific function of the enzyme nitrite oxidoreductase in the nitrogen cycle?
(A) Reduction of nitrite to nitric oxide
(B) Oxidation of hydroxylamine to nitrite
(C) Reduction of nitrate to ammonia
(D) Oxidation of nitrite to nitrate

2019

55. Denitrification is detrimental to agricultural productivity but ecologically vital. Which gas is an obligate intermediate that often escapes during incomplete denitrification?
(A) Dinitrogen (N_2)
(B) Nitrous oxide (N_2O)
(C) Oxygen (O_2)
(D) Hydrogen sulfide (H_2S)

2004

56. Which statement most accurately contrasts nitrification and denitrification?
(A) Nitrification requires anaerobic conditions, whereas denitrification is strictly aerobic.
(B) Nitrification is an oxidative process, whereas denitrification is a reductive process.
(C) Both processes are carried out by identical autotrophic bacteria.
(D) Both processes increase the total available nitrogen pool in the soil.

2003

57. The anammox process contributes significantly to the marine nitrogen cycle. What is the fundamental biochemical reaction of anammox?
(A) Anaerobic oxidation of ammonium using nitrite to produce dinitrogen gas
(B) Aerobic reduction of nitrate to ammonium
(C) Conversion of organic nitrogen directly into nitrate
(D) Reduction of dinitrogen to ammonia

2011

58. Which crucial environmental factor drastically accelerates the rate of soil denitrification?
(A) High soil aeration and low moisture
(B) Extreme soil acidity below pH 3.0
(C) Complete absence of organic matter
(D) Waterlogged, anaerobic soil conditions

2024

59. In the context of ammonification, which extracellular enzymes are primarily secreted by soil microbes to degrade proteinaceous organic matter?
(A) Proteases
(B) Cellulases
(C) Amylases
(D) Lipases

2018

60. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).

Assertion (A) : Nitrification tends to acidify the soil.

Reason (R) : The oxidation of ammonium to nitrate releases protons (H^+) into the soil solution.

(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2019

61. Plant nitrate reductase (NR) is a homodimeric enzyme. Which three prosthetic groups constitute the electron transport chain within each subunit of NR?

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(A) FAD, Heme, and Molybdopterin
(B) NAD, Fe-S cluster, and Copper
(C) FMN, Heme, and Zinc
(D) FAD, Fe-S cluster, and Molybdopterin

2002

62. What is the physiological consequence of an environmental shift to darkness on plant nitrate reductase activity?
(A) It undergoes rapid irreversible proteolysis.
(B) It is activated via dephosphorylation.
(C) It is inactivated by phosphorylation and subsequent binding of 14-3-3 proteins.
(D) It detaches from the plasma membrane into the vacuole.

2012

63. Nitrate reductase catalyzes the reduction of nitrate to nitrite. Where is this enzyme primarily localized in a typical leaf mesophyll cell?
(A) Cytosol
(B) Chloroplast stroma
(C) Mitochondrial matrix
(D) Peroxisome

2018

64. Nitrite produced in the cytosol is highly toxic. How does the plant cell ensure it does not accumulate?
(A) Immediate export out of the cell via efflux carriers
(B) Sequestration into the central vacuole
(C) Conversion back to nitrate by cytosolic nitrite oxidoreductase
(D) Rapid transport into the chloroplast for further reduction

2018

65. Plant nitrite reductase (NiR) catalyzes a six-electron reduction. What are the specific prosthetic groups of NiR?
(A) Siroheme and a [4Fe-4S] cluster
(B) FAD and Molybdopterin
(C) Copper and Heme a
(D) Pyridoxal phosphate and Zinc

2022

66. What is the primary physiological electron donor for nitrite reductase in photosynthetic leaf tissues?
(A) NADH
(B) NADPH
(C) Reduced glutathione
(D) Reduced ferredoxin

NODIA

2025

67. In non-photosynthetic root tissues, where does nitrite reduction occur and what is the electron source?
(A) Proplastids using ferredoxin reduced by the oxidative pentose phosphate pathway
(B) Cytosol using NADH
(C) Mitochondria using FADH2
(D) Vacuoles using ATP

2008

68. Identify the INCORRECT statement regarding the regulation of nitrate assimilation enzymes.
(A) Light stimulates the transcription and activation of NR.
(B) High levels of glutamine and other amino acids act as positive feed-forward activators of NR.
(C) Nitrate induces the transcription of both NR and NiR genes.
(D) The phosphorylation status of NR critically controls its activity.

2007

69. A mutation causing defective molybdopterin synthesis will most immediately compromise the function of which enzyme?
(A) Nitrate reductase
(B) Nitrite reductase
(C) Glutamine synthetase
(D) Glutamate synthase

2003

70. Match the enzyme or protein in List I with its function in nitrate assimilation in List II.
List I : (Enzyme/Protein)
P. Nitrate Reductase
Q. Nitrite Reductase
R. 14-3-3 protein
S. Ferredoxin
List II : (Function)
1. Inhibits NR upon binding
2. Reduces nitrite to ammonium
3. Provides electrons for NiR in chloroplasts
4. Reduces nitrate to nitrite
(A) P-II, Q-IV, R-I, S-III
(B) P-I, Q-III, R-II, S-IV
(C) P-IV, Q-II, R-I, S-III
(D) P-IV, Q-I, R-III, S-II

2025

71. Which condition would most likely lead to toxic accumulation of nitrite in a plant cell?
(A) High light intensity and abundant carbon dioxide
(B) Optimal supply of molybdenum and iron

(C) High activity of glutamine synthetase
(D) Sudden transition to anaerobiosis or flooding

2006

72. Which product is the immediate outcome of the nitrate reductase catalyzed reaction?
(A) Ammonium
(B) Nitrite
(C) Nitrogen gas
(D) Amino acids

2012

73. Which of the following is a classic example of a free-living, aerobic nitrogen-fixing bacterium?
(A) Azotobacter chroococcum
(B) Clostridium pasteurianum
(C) Klebsiella pneumoniae
(D) Rhizobium leguminosarum

2014

74. Associative nitrogen fixation is highly significant in tropical grasses. Which bacterium is prominently known for its associative symbiosis with roots of sugarcane and maize?
(A) Frankia
(B) Nitrobacter winogradskyi
(C) Bradyrhizobium japonicum
(D) Azospirillum brasilense

2006

75. Unlike symbiotic rhizobia, free-living diazotrophs must independently protect their nitrogenase from oxygen. How does Azotobacter achieve this?
(A) By residing strictly in deep, anaerobic soil layers
(B) By maintaining an exceptionally high rate of respiration
(C) By producing leghaemoglobin
(D) By ceasing all metabolic activity in the presence of oxygen

2011

76. Which free-living bacterium relies on spatial separation of nitrogen fixation and photosynthesis by using specialized cells called heterocysts?
(A) Pseudomonas
(B) Rhodospirillum
(C) Anabaena
(D) Azotobacter

2023

77. Which energy-yielding metabolic pathway primarily supports nitrogen fixation in the obligate anaerobe Clostridium pasteurianum?
(A) Fermentation
(B) Oxidative phosphorylation
(C) Oxygenic photosynthesis
(D) Chemoautotrophy

2018

78. Identify the INCORRECT statement regarding non-symbiotic nitrogen fixation.
(A) Nitrogenase expression is upregulated in the presence of high external ammonium.
(B) It contributes less total nitrogen globally compared to symbiotic fixation.
(C) Diazotrophs require large amounts of ATP to fix atmospheric nitrogen.
(D) Some free-living diazotrophs are photosynthetic.

2011

79. What biochemical mechanism regulates the nif (nitrogen fixation) gene operon in free-living bacteria like Klebsiella in response to high oxygen or fixed nitrogen?
(A) Repression by the NifL-NifA two-component regulatory system
(B) Positive feedback by glutamine
(C) Constitutive expression regardless of environment
(D) Post-translational cleavage of nitrogenase

2001

80. Consider the following bacteria:
I. Azotobacter
II. Beijerinckia
III. Frankia
Which of the above represents strictly free-living diazotrophs?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2007

81. In associative symbiosis, the plant host often provides the bacteria with carbon sources. What form of carbon do tropical grasses typically exude to support Azospirillum?
(A) Organic acids like malate and succinate
(B) Complex lignin polymers
(C) Starches
(D) Waxes and suberins

2005

82. Which non-symbiotic diazotroph is a facultative anaerobe, capable of fixing nitrogen only under anaerobic or microaerophilic conditions?
(A) Azotobacter
(B) Klebsiella pneumoniae

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(C) Cyanothece
(D) Nitrosomonas

2018

83. Cyanobacteria can perform both oxygenic photosynthesis and nitrogen fixation. How do non-heterocystous cyanobacteria like Trichodesmium resolve the oxygen conflict?
(A) By strictly fixing nitrogen in the dark (temporal separation)
(B) By mutating nitrogenase to be oxygen-insensitive
(C) By abandoning photosynthesis entirely
(D) By forming symbiotic nodules on roots

2002

84. Which microelement is uniquely required in higher concentrations by free-living diazotrophs to synthesize the primary cofactor of nitrogenase?
(A) Molybdenum
(B) Zinc
(C) Copper
(D) Cobalt

2021

85. During the initiation of symbiotic nitrogen fixation, what is the primary function of plant-secreted flavonoids?
(A) Inducing the expression of nodulation (nod) genes in rhizobia
(B) Directly lysing the bacterial cell wall
(C) Inhibiting root hair growth
(D) Providing a sole carbon source for bacterial respiration

2025

86. What is the basic biochemical structure of the Nod factors secreted by rhizobia?
(A) Lipo-chitooligosaccharides
(B) Small cyclic peptides
(C) Poly-beta-hydroxybutyrates
(D) Steroid hormones

2007

87. Identify the earliest observable morphological response of a compatible plant root to purified Nod factors.
(A) Cortical cell death
(B) Shedding of the root cap
(C) Root hair deformation and curling
(D) Emergence of a mature nodule

2016

88. How do the invading rhizobia typically travel from the curled root hair into the root cortex?
(A) Via a newly synthesized intracellular tubular structure called the infection thread
(B) Through plasmodesmata between epidermal cells
(C) By dissolving the middle lamella and moving apoplastically
(D) By hijacking the xylem transpiration stream

2009

89. Inside the mature root nodule, rhizobia differentiate into morphologically distinct, nitrogen-fixing forms known as what?
(A) Bacteroids
(B) Endospores
(C) Heterocysts
(D) Protoplasts

2021

90. Consider the following properties of leghaemoglobin:
I. It is an oxygen-binding hemoprotein.
II. It maintains a low free oxygen concentration in the infected cell.
III. It completely inhibits the respiration of bacteroids.
IV. Its heme moiety is synthesized by the bacteria, while the globin is plant-derived.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, III and IV
(C) II, III and IV
(D) I and IV

NODIA

2016

91. In legumes that transport nitrogen as amides, which two amino acid derivatives are the primary export forms from the nodule?
(A) Asparagine and Glutamine
(B) Allantoin and Allantoic acid
(C) Glycine and Serine
(D) Proline and Arginine

2025

92. Tropical legumes like soybeans typically export fixed nitrogen as ureides. In which subcellular organelle does the final synthesis of allantoin occur?
(A) Mitochondria
(B) Nucleus
(C) Chloroplast
(D) Peroxisome

2011

93. Frankia establishes symbiotic nitrogen-fixing root nodules in certain non-leguminous plants. What are these host plants generally called?
(A) Actinorhizal plants

2012

134. Which phase of the cell cycle is typically the longest and represents the primary period of cellular growth and metabolic activity prior to DNA replication?
(A) G1 phase
(B) M phase
(C) G2 phase
(D) Cytokinesis

2003

135. Plant cells possess a unique structure during late G2 phase that accurately predicts the future plane of cell division. What is this structure?
(A) The preprophase band (PPB)
(B) The phragmoplast
(C) The cell plate
(D) The spindle apparatus

2012

136. Which cytological event distinctly marks the transition from metaphase to anaphase during mitosis?
(A) Breakdown of the nuclear envelope
(B) Condensation of chromatin
(C) Formation of the nucleolus
(D) Separation of sister chromatids

2001

137. Unlike animal cells, plant cells accomplish cytokinesis through the formation of a cell plate. Which organelle is predominantly responsible for delivering the necessary materials to form the cell plate?
(A) Golgi apparatus
(B) Mitochondria
(C) Chloroplasts
(D) Lysosomes

2013

138. The structure that guides the fusion of Golgi-derived vesicles to form the cell plate during plant cytokinesis is known as what?
(A) Phragmoplast
(B) Preprophase band
(C) Kinetochore
(D) Centrosome

2017

139. Certain plant tissues undergo continuous rounds of DNA replication without cell division, leading to polyploidy. What is this variant cell cycle called?
(A) Endoreduplication
(B) Meiosis
(C) Apoptosis
(D) Amitosis

2006

140. Consider the following statements about plant cell cycle transitions:
I. The G1/S transition controls entry into DNA synthesis.
II. The G2/M transition regulates entry into mitosis.
III. The spindle assembly checkpoint occurs during the S phase.
IV. Progression through checkpoints is completely independent of environmental signals.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I and II
(C) II, III and IV
(D) I, III and IV

2010

141. Cells that exit the active cell cycle and undergo differentiation without further division are said to be in which phase?
(A) G0 phase
(B) S phase
(C) G2 arrest
(D) Telophase

2005

142. The strict sequence of cell cycle phases is essential for genome stability. Which statement correctly describes the G2 phase?
(A) It is a gap phase between DNA replication and mitosis used for checking DNA integrity.
(B) It is the phase where cytokinesis physically separates the cells.
(C) It is the phase of primary cell wall deposition.
(D) It is characterized by active pairing of homologous chromosomes.

2019

143. Which specific microtubule-organizing structures are absent in higher plant cells, contrasting them with animal cells during spindle formation?
(A) Centrioles / Centrosomes
(B) Kinetochores
(C) Phragmoplasts
(D) Microfilaments

2022

144. Identify the phase where the nuclear envelope fully reforms around the two distinct sets of daughter chromosomes.
(A) Telophase
(B) Prophase

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(D) Acetylene stabilizes nitrogenase against oxygen denaturation.

2017

104. Nitrogenase is extremely sensitive to oxygen. What structural feature at the molecular level makes the MoFe protein vulnerable to O_2?
(A) Irreversible oxidation of the essential iron-sulfur clusters
(B) Denaturation of the polypeptide backbone
(C) Competitive binding of O_2 to the ATP hydrolysis site
(D) Cleavage of the molybdopterin cofactor

2003

105. Apart from the standard Mo-dependent nitrogenase, what alternative metal-dependent nitrogenases exist in some diazotrophs under Mo deficiency?
(A) Vanadium- and Iron-only nitrogenases
(B) Zinc- and Copper-dependent nitrogenases
(C) Cobalt- and Nickel-dependent nitrogenases
(D) Manganese-dependent nitrogenase

2017

106. In the stoichiometry of biological nitrogen fixation, how many electrons are required at a minimum to reduce one N_2 and produce one H_2?
(A) 4
(B) 6
(C) 8
(D) 10

2012

107. Which component is responsible for the conformational change that drives the transfer of electrons from the Fe protein to the MoFe protein?
(A) Binding and hydrolysis of ATP on the Fe protein
(B) Binding of N_2 to the MoFe protein
(C) Oxidation of ferredoxin
(D) Release of ammonia

2022

108. The P-cluster in the MoFe protein serves what primary function?
(A) It acts as an electron storage and transfer intermediate between the Fe protein and the FeMo-cofactor.
(B) It is the site of ATP hydrolysis.
(C) It specifically binds the dinitrogen molecule.
(D) It protects the enzyme from reactive oxygen species.

2003

109. What biochemical reaction is catalyzed by the uptake hydrogenase enzyme in diazotrophs?
(A) Reduction of protons to hydrogen gas
(B) Oxidation of hydrogen gas to yield protons and electrons
(C) Fixation of nitrogen using hydrogen gas
(D) Synthesis of water from hydrogen and oxygen

2004

110. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Diazotrophs possessing an active uptake hydrogenase (Hup^+) generally show higher energy efficiency in nitrogen fixation.
Reason (R) : Uptake hydrogenase recycles the obligatory hydrogen gas produced by nitrogenase, recovering electrons and some ATP.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

NODIA

2017

111. Where is the uptake hydrogenase primarily localized within the bacteroid?
(A) Inner membrane facing the periplasmic space
(B) Cytosol
(C) Outer membrane
(D) Free within the symbiosome space

2018

112. Uptake hydrogenase in rhizobia is typically a metalloenzyme requiring which two specific metals at its active site?
(A) Iron and Copper
(B) Zinc and Cobalt
(C) Nickel and Iron
(D) Molybdenum and Iron

2011

113. What is a secondary physiological benefit of the uptake hydrogenase reaction in root nodules, besides energy recovery?
(A) It produces oxygen for respiration.
(B) It synthesizes leghemoglobin.
(C) It fixes carbon dioxide into malate.
(D) It helps consume oxygen, aiding in the protection of nitrogenase.

2021

114. Which electron acceptor within the bacteroid respiratory chain typically receives electrons from the uptake hydrogenase?
(A) Cytochrome b or ubiquinone pool
(B) NAD^+
(C) Ferredoxin
(D) Flavodoxin

2011

115. Identify the condition that generally represses the expression of the hup (hydrogen uptake) genes in rhizobia.
(A) High availability of carbon and absence of hydrogen
(B) Low oxygen tension
(C) Presence of hydrogen gas
(D) Nickel availability

2016

116. In agricultural terms, why is inoculating legumes with Hup+ (hydrogenase-positive) strains of rhizobia considered advantageous?
(A) They fix nitrogen independent of molybdenum.
(B) They cause larger, tumor-like nodules.
(C) They prevent the necessity of nodule formation entirely.
(D) They improve total dry matter yield by minimizing energy lost as evolved hydrogen gas.

2002

117. What consequence arises in Hup- (hydrogenase-negative) bacteroids during active nitrogen fixation?
(A) Hydrogen gas evolves out of the nodule into the surrounding soil.
(B) They completely fail to fix nitrogen.
(C) Nitrogenase is immediately poisoned by the hydrogen.
(D) They switch to fermentative metabolism.

2015

118. Which statement about the structure of a typical NiFe-uptake hydrogenase is correct?
(A) It consists of a large subunit containing the NiFe active site and a small subunit with Fe-S clusters.
(B) It is a homodimer with identical subunits.
(C) It lacks any iron-sulfur clusters.
(D) It requires a continuous supply of ATP to function.

2010

119. How do hydrogen gas evolution by Hup- nodules impact the surrounding soil ecosystem?
(A) It severely acidifies the root zone.
(B) It can stimulate the growth of distinct hydrogen-oxidizing soil bacteria.
(C) It acts as a potent fungicide.
(D) It totally displaces oxygen, killing the plant roots.

2007

120. Match the physiological feature in List I with its corresponding enzyme in List II.
List I : (Feature)
P. Produces obligatory H_2
Q. Consumes H_2
R. Protects against O_2 locally
S. Synthesizes glutamine
List II : (Enzyme/Protein)
1. Uptake Hydrogenase
2. Nitrogenase
3. Glutamine Synthetase
4. Leghaemoglobin
(A) P-II, Q-I, R-IV, S-III
(B) P-I, Q-II, R-III, S-IV
(C) P-II, Q-IV, R-I, S-III
(D) P-I, Q-III, R-IV, S-II

2008

121. Chemoautotrophic nitrifying bacteria derive their cellular carbon primarily from which source?
(A) Atmospheric carbon dioxide (CO_2)
(B) Organic matter exudates
(C) Methane
(D) Amino acids

2004

122. Which primary biochemical pathway do Nitrosomonas and Nitrobacter employ to fix carbon dioxide?
(A) Calvin cycle
(B) Reductive TCA cycle
(C) Wood-Ljungdahl pathway
(D) 3-Hydroxypropionate cycle

2022

123. The energy required for carbon fixation in Nitrosomonas is derived from what specific process?
(A) Oxidation of ammonia to nitrite
(B) Oxidation of nitrite to nitrate
(C) Sunlight absorption by bacteriochlorophyll
(D) Fermentation of sugars

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2004

124. Chemoautotrophs face a thermodynamic challenge in producing NADH because their inorganic electron donors have a higher redox potential than NAD^+. How do they overcome this?
(A) By relying strictly on ATP instead of NADH
(B) By absorbing light energy to boost electron potential
(C) By using fermentation pathways to generate NADH
(D) By utilizing reverse electron transport driven by the proton motive force

2005

125. Identify the INCORRECT statement regarding chemoautotrophy in rhizobia.
(A) Chemoautotrophy is the primary energy mode for rhizobia inside the root nodule.
(B) Bradyrhizobium japonicum can act as a chemoautotroph by oxidizing H_2 to fix CO_2 under specific free-living conditions.
(C) Chemoautotrophic growth in rhizobia requires both uptake hydrogenase and RuBisCO.
(D) The process allows survival in carbon-poor, hydrogen-rich soil environments.

2022

126. Which key enzyme must be present and active for a bacterium to be considered a true chemoautotroph using the Calvin cycle?
(A) PEP carboxylase
(B) Ribulose-1,5-bisphosphate carboxylase/ oxygenase (RuBisCO)
(C) Ammonia monooxygenase
(D) Nitrogenase

2004

127. Why are nitrifying bacteria generally slow-growing compared to heterotrophic bacteria?
(A) The energy yield from the oxidation of inorganic nitrogen compounds is very low.
(B) Their generation time is limited by the fast rate of diffusion.
(C) They must synthesize complex organic compounds exclusively in the dark.
(D) They strictly require high temperatures for cell division.

2010

128. What is the terminal electron acceptor in the respiratory chain of aerobic chemoautotrophic nitrifiers?
(A) Oxygen (O_2)
(B) Nitrate
(C) Sulfate
(D) Carbon dioxide

2005

129. The oxidation of hydroxylamine to nitrite by Nitrosomonas releases electrons. Where do these electrons immediately go?
(A) Cytochrome c pool
(B) Directly to NAD^+
(C) RuBisCO
(D) Plastoquinone

2008

130. Consider the following statements concerning Nitrobacter:
I. It is a chemoautotroph that fixes CO_2.
II. It derives energy by oxidizing nitrite to nitrate.
III. It uses sunlight as a supplementary energy source.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2007

131. In the context of energy efficiency, why does Nitrosomonas have a higher cellular yield per mole of substrate oxidized than Nitrobacter?
(A) Ammonia oxidation yields more energy than nitrite oxidation.
(B) Nitrosomonas does not need to fix carbon.
(C) Nitrobacter lacks an electron transport chain.
(D) Nitrosomonas utilizes anaerobic respiration.

2001

132. How do nitrifying bacteria typically store excess fixed carbon during optimal conditions?
(A) As poly-beta-hydroxybutyrate (PHB) or glycogen-like polymers
(B) As massive starch granules
(C) As lipid droplets
(D) As extracellular mucilage

2017

133. The eukaryotic plant cell cycle consists of four distinct phases. In which phase does chromosomal DNA replication occur?
(A) S phase
(B) G1 phase
(C) G2 phase
(D) M phase

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(B) Mycorrhizal plants
(C) Epiphytes
(D) Parasitic plants

2019

94. What is the role of the symbiosome membrane (peribacteroid membrane) in a mature nodule?
(A) It facilitates the exchange of fixed nitrogen for plant dicarboxylic acids.
(B) It strictly prevents the exchange of nutrients.
(C) It actively pumps oxygen into the bacteroid.
(D) It degrades senescent bacteria.

2008

95. The specificity of the legume-rhizobium symbiosis is primarily determined at which stage?
(A) Flavonoid secretion and specific Nod factor recognition
(B) Nitrogenase assembly
(C) Leghaemoglobin synthesis
(D) Phloem transport of sucrose

2022

96. What triggers the transition from a vegetative rhizobium to a differentiated bacteroid within the symbiosome?
(A) High external light intensity
(B) Plant-derived nodule-specific cysteine-rich (NCR) peptides
(C) Complete absence of carbon sources
(D) Secretion of toxic heavy metals by the host

2011

97. The nitrogenase enzyme complex consists of two major protein components. What are they?
(A) Dinitrogenase (MoFe protein) and Dinitrogenase reductase (Fe protein)
(B) Nitrate reductase and Nitrite reductase
(C) Glutamine synthetase and Glutamate synthase
(D) Leghemoglobin and Cytochrome oxidase

2023

98. What is the fundamental catalytic role of the Fe protein in the nitrogenase complex?
(A) It binds molecular nitrogen directly.
(B) It hydrolyzes ATP to transfer electrons to the MoFe protein.
(C) It exclusively reduces protons to hydrogen gas.
(D) It synthesizes the FeMo-cofactor.

2010

99. How many moles of ATP are theoretically required to reduce one mole of N_2 to two moles of NH_3 by the nitrogenase complex?
(A) 4
(B) 8
(C) 16
(D) 32

NODIA

2014

100. Consider the following statements about the nitrogenase mechanism:
I. The reduction of N_2 requires significant ATP despite being a thermodynamically exergonic overall reaction.
II. Nitrogenase irreversibly loses activity upon exposure to O_2.
III. The enzyme produces at least one mole of H_2 for every mole of N_2 reduced.
IV. Carbon monoxide is a potent inhibitor of N_2 reduction.
V. The Fe protein accepts electrons directly from water.
Which of the above statement(s) is/are correct?
(A) I, II, III and V
(B) I, II, III and IV
(C) II, III, IV and V
(D) I, III and IV

2024

101. Which metal cluster constitutes the actual active site where dinitrogen binds and is reduced within the MoFe protein?
(A) The FeMo-cofactor (FeMoco)
(B) The P-cluster (8Fe-7S)
(C) The Rieske Fe-S center
(D) The binuclear copper center

2008

102. Identify the INCORRECT statement regarding the substrates of nitrogenase.
(A) Nitrogenase can reduce acetylene to ethylene.
(B) Nitrogenase strictly reduces only dinitrogen gas.
(C) Nitrogenase can reduce azide to ammonia and dinitrogen.
(D) Nitrogenase obligatorily reduces protons to hydrogen gas.

2005

103. Why is the acetylene reduction assay widely used in nitrogen fixation research?
(A) Ethylene, the product, is easily quantified by gas chromatography as a surrogate measure of nitrogenase activity.
(B) Acetylene provides energy for the nitrogenase complex.
(C) It completely prevents the enzyme from producing hydrogen.

(C) Metaphase
(D) Anaphase

2019

145. The molecular progression of the plant cell cycle is fundamentally driven by the periodic activation of which class of enzymes?
(A) Cyclin-dependent kinases (CDKs)
(B) MAP kinases
(C) Tyrosine phosphatases
(D) DNA polymerases

2008

146. How do cyclins primarily regulate the activity of CDKs?
(A) By acting as the regulatory subunit that must bind to CDK for its catalytic activity
(B) By degrading the CDK protein after each phase
(C) By phosphorylating the CDK
(D) By serving as competitive inhibitors at the active site

2019

147. In higher plants, the G1/S transition is notably controlled by the interaction of CDKA with which specific class of cyclins?
(A) D-type cyclins
(B) A-type cyclins
(C) B-type cyclins
(D) H-type cyclins

2012

148. Which protein complex is responsible for the targeted destruction of specific cyclins to drive the transition out of mitosis?
(A) The Anaphase-Promoting Complex/ Cyclosome (APC/C)
(B) The Origin Recognition Complex (ORC)
(C) The Retinoblastoma-related (RBR) protein complex
(D) The MCM helicase complex

2016

149. The plant retinoblastoma-related (RBR) protein controls the entry into S phase. How does CDK-cyclin activity affect RBR?
(A) It phosphorylates RBR, releasing E2F transcription factors to promote S phase genes.
(B) It activates RBR to block DNA synthesis.
(C) It degrades RBR completely.
(D) It transports RBR out of the nucleus.

2022

150. Consider the following factors:
I. Cyclin binding
II. Kip-related proteins (KRPs)
III. WEE1 kinase phosphorylation
IV. APC/C mediated proteolysis
V. CDK-activating kinase (CAK) phosphorylation
Which of the above correctly describes factors that strictly inhibit CDK activity?
(A) II, III and IV
(B) I, II and III
(C) III, IV and V
(D) I, IV and V

2017

151. Which plant hormone heavily influences the D-type cyclins (CYCD) to link environmental and developmental signals to the initiation of the cell cycle?
(A) Cytokinin
(B) Ethylene
(C) Abscisic acid
(D) Salicylic acid

2021

152. Endoreduplication occurs when a cell bypasses mitosis. Molecularly, this is often driven by the downregulation of which specific complex?
(A) Mitotic CDK-Cyclin B complex
(B) G1 CDK-Cyclin D complex
(C) DNA polymerase alpha
(D) E2F-DP transcription factors

2017

153. What is the role of WEE1 kinase in the molecular regulation of the plant cell cycle?
(A) It phosphorylates and inhibits CDK to arrest the cell cycle in response to DNA damage.
(B) It dephosphorylates CDK to rapidly trigger mitosis.
(C) It forms the structural core of the preprophase band.
(D) It synthesizes cyclins during S phase.

2014

154. The transition from G2 to M phase in plants is primarily regulated by the activation of CDKA or CDKB complexed with which cyclins?
(A) A-type and B-type cyclins
(B) D-type cyclins
(C) C-type cyclins
(D) E-type cyclins

2014

155. Which plant-specific class of CDKs is distinguished by its strict accumulation only

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2007

217. The hypersensitive response (HR) is a hallmark of plant defense. What defines HR biochemically and cytologically?
(A) Rapid, localized programmed cell death at the site of pathogen infection
(B) Extensive proliferation of plant cells to form a tumor
(C) Systemic shedding of infected leaves
(D) Accelerated photosynthesis in infected cells

2021

218. The perception of Pathogen-Associated Molecular Patterns (PAMPs) such as flagellin by plant pattern recognition receptors (PRRs) initiates which basal defense layer?
(A) PAMP-Triggered Immunity (PTI)
(B) Effector-Triggered Immunity (ETI)
(C) Systemic Acquired Resistance (SAR)
(D) Induced Systemic Resistance (ISR)

2019

219. Pathogens deliver effector proteins to suppress PTI. In response, plants evolved Resistance (R) proteins that recognize these effectors, leading to a much stronger defense called Effector-Triggered Immunity (ETI). Most plant R proteins possess which structural domains?
(A) Nucleotide-binding site and Leucine-rich repeats (NBS-LRR)
(B) Kinase-only domains
(C) Zinc fingers
(D) Basic helix-loop-helix (bHLH)

2011

220. Match the plant defense molecule in List I with its description in List II.
List I : (Molecule)
P. Phytoalexin
Q. Salicylic Acid
R. Chitinase
S. Callose
List II : (Description)
1. Beta-1,3-glucan polymer deposited to reinforce cell walls
2. Pathogenesis-related (PR) protein that degrades fungal cell walls
3. Low molecular weight antimicrobial synthesized de novo after infection
4. Systemic signaling hormone for SAR
(A) P-IV, Q-III, R-I, S-II
(B) P-II, Q-I, R-IV, S-III
(C) P-III, Q-IV, R-II, S-I
(D) P-I, Q-II, R-III, S-IV

2013

221. Phytoalexins are diverse secondary metabolites. What structural class of phytoalexins is predominantly produced by the Leguminosae (legume) family?
(A) Isoflavonoids (e.g., pisatin, glyceollin)
(B) Diterpenes (e.g., casbene)
(C) Sesquiterpenes (e.g., rishitin)
(D) Glucosinolates

2017

222. Systemic Acquired Resistance (SAR) provides long-lasting, broad-spectrum resistance throughout the plant following an initial localized infection. Which key regulatory protein strictly controls SAR gene expression downstream of salicylic acid?
(A) NPR1 (Non-expresser of PR genes 1)
(B) COI1
(C) JAZ
(D) EIN2

2002

223. The oxidative burst is an extremely rapid event during plant-pathogen interactions. Which enzyme complex on the plasma membrane is primarily responsible for generating the initial superoxide burst?
(A) NAD(P)H oxidase (RBOH)
(B) Alternative oxidase (AOX)
(C) Cytochrome c oxidase
(D) Lipoxygenase

2010

224. Induced Systemic Resistance (ISR) is distinct from SAR. What uniquely triggers ISR and which hormones mediate it?
(A) Triggered by beneficial rhizobacteria; mediated by jasmonic acid and ethylene
(B) Triggered by necrotizing pathogens; mediated by salicylic acid
(C) Triggered by abiotic stress; mediated by abscisic acid
(D) Triggered by chewing herbivores; mediated by auxins

2006

225. Many Pathogenesis-Related (PR) proteins possess direct antimicrobial activity. Which of the following is an expected activity of PR-2 or PR-3 type proteins against fungal pathogens?
(A) Hydrolysis of beta-1,3-glucans and chitin
(B) Inhibition of viral RNA polymerase
(C) Degradation of bacterial flagellin
(D) Cleavage of host DNA

NODIA

newly synthesized matrix polysaccharides to the expanding cell wall?
(A) Exocytosis of secretory vesicles from the Golgi network
(B) Direct synthesis by plasma membrane rosettes
(C) Passive diffusion from adjacent cells
(D) Translocation via plasmodesmata

2012

166. Identify the INCORRECT statement regarding plant growth and cellular expansion.
(A) Expansion can proceed indefinitely without the uptake of water.
(B) Cell wall yielding strictly requires the breakage and reformation of load-bearing cross-links.
(C) Anisotropic growth (expansion primarily in one direction) is dictated by the orientation of cellulose microfibrils.
(D) Growth ceases when the wall hardens and secondary cell wall layers are deposited.

2015

167. Which term defines the developmental phenomenon where the main central stem of the plant grows more strongly than the side stems?
(A) Apical dominance
(B) Parthenocarpy
(C) Senescence
(D) Photoperiodism

2012

168. Thigmotropism is the directional growth response to touch, highly visible in tendrils. Which two hormones act cooperatively to regulate this rapid coiling response?
(A) Auxin and Ethylene
(B) Gibberellin and Abscisic acid
(C) Cytokinin and Salicylic acid
(D) Jasmonate and Brassinosteroid

2024

169. What is the primary biosynthetic precursor for the most abundant natural auxin, Indole-3-acetic acid (IAA)?
(A) Tryptophan
(B) Tyrosine
(C) Methionine
(D) Phenylalanine

2017

170. Match the phytohormone in List I with its classic physiological role in List II.
List I : (Hormone)
P. Auxin
Q. Gibberellin
R. Cytokinin
S. Abscisic Acid
List II : (Role)
1. Delay of leaf senescence
2. Apical dominance and root initiation
3. Stomatal closure during drought
4. Bolting and internode elongation
(A) P-I, Q-II, R-III, S-IV
(B) P-II, Q-IV, R-I, S-III
(C) P-III, Q-I, R-IV, S-II
(D) P-II, Q-III, R-I, S-IV

2017

171. The polar transport of auxin (basipetal movement) in stems is strictly mediated by the asymmetric cellular localization of which specific efflux carrier proteins?
(A) PIN proteins
(B) AUX1 permeases
(C) ABC transporters
(D) Aquaporins

2025

172. Gibberellins (GAs) are structurally complex tetracyclic diterpenes. In which subcellular compartments does their biosynthetic pathway sequentially occur?
(A) Plastid, Endoplasmic Reticulum, and Cytosol
(B) Mitochondria, Vacuole, and Nucleus
(C) Cytosol only
(D) Chloroplast and Nucleus

2013

173. Which key enzyme in the gibberellin biosynthesis pathway is a major target for commercial growth retardants?
(A) Ent-kaurene oxidase
(B) Ent-copalyl diphosphate synthase
(C) GA 20-oxidase
(D) GA 3-oxidase

2018

174. In cereal grain germination, gibberellins secreted by the embryo diffuse to the aleurone layer to stimulate the synthesis of which crucial enzyme?
(A) Alpha-amylase
(B) Lipase
(C) Protease
(D) Pectinase

2018

175. Cytokinins are adenine derivatives. What is the common precursor molecule utilized by

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isopentenyl transferase (IPT) to synthesize the active cytokinin backbone?
(A) ATP or ADP and dimethylallyl diphosphate (DMAPP)
(B) ADP and geranyl diphosphate
(C) AMP and farnesyl pyrophosphate
(D) Cyclic AMP and zeaxanthin

2002

176. Which natural cytokinin is the most abundant and universally found in higher plants?
(A) Zeatin
(B) Kinetin
(C) Benzyladenine (BA)
(D) Thidiazuron

2008

177. The ratio of which two phytohormones critically determines organogenesis (root vs. shoot differentiation) in plant tissue culture?
(A) Auxin and Cytokinin
(B) Auxin and Gibberellin
(C) Cytokinin and Ethylene
(D) Gibberellin and Abscisic acid

2018

178. Cytokinins are predominantly synthesized in which plant organ before being transported via the xylem to the shoot?
(A) Root apical meristem
(B) Shoot apical meristem
(C) Mature leaves
(D) Floral primordia

2001

179. Auxin profoundly impacts vascular tissue differentiation. High concentrations of auxin primarily induce the differentiation of which vascular tissue?
(A) Xylem
(B) Phloem
(C) Cork cambium
(D) Endodermis

2006

180. Select the correct sequence of intermediates in the primary tryptophan-dependent pathway for IAA biosynthesis.
(A) Tryptophan → Indole-3-pyruvate (IPyA) → Indole-3-acetic acid (IAA)
(B) Tryptophan → Indole-3-acetonitrile (IAN) → Indole-3-pyruvate (IPyA) → IAA
(C) Tryptophan → Tryptamine → Indole-3-acetaldehyde → IAA
(D) Tryptophan → Indole-3-acetamide (IAM) → IPyA → IAA

2022

181. What is the direct 15-carbon biosynthetic precursor of Abscisic acid (ABA), resulting from the cleavage of a 40-carbon carotenoid?
(A) Xanthoxin
(B) Farnesyl diphosphate
(C) Zeaxanthin
(D) Violaxanthin

2001

182. Ethylene is a simple gaseous hormone. Which amino acid serves as its direct precursor in higher plants?
(A) Methionine
(B) Serine
(C) Cysteine
(D) Glycine

2005

183. Which enzyme catalyzes the rate-limiting step in ethylene biosynthesis, converting S-adenosylmethionine (SAM) to 1-aminocyclopropane-1-carboxylic acid (ACC)?
(A) ACC synthase
(B) ACC oxidase
(C) SAM synthetase
(D) Methionine synthase

2018

184. Brassinosteroids (BRs) are plant steroid hormones essential for normal growth. From which universal sterol precursor are they synthesized?
(A) Campesterol
(B) Cholesterol
(C) Ergosterol
(D) Stigmasterol

2006

185. Jasmonic acid (JA) is structurally similar to animal prostaglandins and is primarily involved in defense responses. From which fatty acid is JA derived?
(A) Linolenic acid
(B) Palmitic acid
(C) Oleic acid
(D) Stearic acid

NODIA

2019

186. Where does the initial part of the jasmonic acid biosynthetic pathway (up to the formation of OPDA) occur within the plant cell?
(A) Chloroplast
(B) Mitochondria
(C) Peroxisome
(D) Cytosol

2021

187. Which phenomenon is classically referred to as the "triple response" induced by ethylene in etiolated dicot seedlings?
(A) Inhibition of hypocotyl elongation, thickening of the hypocotyl, and exaggerated apical hook
(B) Enhanced root hair growth, accelerated flowering, rapid internode elongation
(C) Leaf abscission, fruit ripening, and senescence
(D) Stomatal closure, root initiation, and seed dormancy

2008

188. Identify the primary physiological trigger that drastically upregulates ABA biosynthesis in leaves.
(A) Water deficit (drought stress)
(B) High light intensity
(C) Flooding
(D) Pathogen infection

2008

189. Which structural mutant classically demonstrates severe dwarfism that can be completely rescued by the exogenous application of brassinosteroids?
(A) The de-etiolated (det2) mutant
(B) The ethylene-insensitive (ein) mutant
(C) The phytochrome-deficient (phyA) mutant
(D) The gibberellin-deficient (ga1) mutant

2023

190. Arrange the following steps of the ethylene biosynthesis pathway in the correct order:
I. Conversion of ACC to Ethylene
II. Synthesis of S-adenosylmethionine (SAM) from Methionine
III. Conversion of SAM to 1-aminocyclopropane-1-carboxylic acid (ACC)
Which of the above correctly order the steps?
(A) I, II, III
(B) II, III, I
(C) III, I, II
(D) II, I, III

2002

191. Which specific developmental process is most uniquely and critically dependent on abscisic acid (ABA)?
(A) Induction and maintenance of seed dormancy
(B) Parthenocarpic fruit development
(C) Breaking of bud dormancy
(D) Rapid cell division in the meristem

2010

192. Jasmonates act antagonistically or synergistically with other hormones. They are generally known to strongly inhibit which fundamental growth process?
(A) Primary root elongation
(B) Root hair formation
(C) Tendril coiling
(D) Trichome initiation

2001

193. The signal transduction pathway for auxin strictly involves which family of repressor proteins that are rapidly degraded upon auxin perception?
(A) Aux/IAA proteins
(B) DELLA proteins
(C) JAZ proteins
(D) WUSCHEL proteins

2010

194. What is the specific role of the TIR1 protein in auxin signaling?
(A) Receptor and F-box component of the SCF complex.
(B) Transcription factor for auxin-responsive genes.
(C) Efflux carrier for auxin at the plasma membrane.
(D) Catabolic enzyme that degrades the auxin signal.

2002

195. In the gibberellin signaling pathway, which repressor proteins are targeted for ubiquitination and degradation by the 26S proteasome upon GA perception?
(A) DELLA proteins
(B) Aux/IAA proteins
(C) JAZ proteins
(D) ARF proteins

2009

196. What is the recognized receptor for gibberellin that undergoes a conformational change to promote DELLA interaction with the SCF E3 ligase?
(A) GID1
(B) TIR1
(C) COI1
(D) BRI1

2009

197. Cytokinin signaling utilizes a modified two-component regulatory system analogous to those in bacteria. Which molecules serve as the primary

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during the G2 and M phases, tightly linking it to mitosis?
(A) CDKB
(B) CDKA
(C) CDKC
(D) CDKE

2001

156. The degradation of key cell cycle proteins occurs via the 26S proteasome. Which molecular tag marks these proteins for destruction?
(A) Ubiquitin
(B) Phosphorylation
(C) Methylation
(D) Acetylation

2006

157. According to the acid growth hypothesis, how do auxins rapidly induce cellular expansion?
(A) By activating H+-ATPases to lower apoplastic pH.
(B) By synthesizing cellulose microfibrils in the wall.
(C) By increasing cellular pH to loosen the membrane.
(D) By degrading the middle lamella using pectinases.

2013

158. What is the specific function of expansins during plant cell growth?
(A) They are non-enzymatic proteins that disrupt hydrogen bonds between cellulose and hemicellulose in a pH-dependent manner.
(B) They are enzymes that cleave cellulose chains.
(C) They actively transport water into the vacuole to increase turgor.
(D) They synthesize new hemicellulose backbones.

2016

159. Cellular expansion inherently requires a driving physical force. Which physiological parameter provides this required force?
(A) Turgor pressure
(B) Transpiration pull
(C) Capillary action
(D) Root pressure

2019

160. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Plant shoots exhibit positive phototropism while roots typically exhibit negative phototropism.
Reason (R) : Asymmetrical distribution of auxin causes differential cell elongation in both tissues, but roots and shoots have opposite sensitivity to auxin concentrations.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

NODIA

2001

161. Phytohormone-based theories explain tropisms through the lateral redistribution of which regulator?
(A) Auxin
(B) Cytokinin
(C) Gibberellin
(D) Ethylene

2010

162. In gravitropism, roots perceive gravity in the root cap. What specialized amyloplasts are responsible for this perception?
(A) Statoliths
(B) Elaioplasts
(C) Chloroplasts
(D) Proteinoplasts

2013

163. How does the asymmetric auxin distribution in a horizontally placed root lead to downward bending?
(A) High auxin on the lower side inhibits cell elongation, while the upper side elongates.
(B) High auxin on the lower side stimulates extreme cell elongation.
(C) Low auxin on the lower side kills the cells.
(D) Auxin accumulation uniformly accelerates growth.

2018

164. Phototropism is initiated by the perception of unidirectional light. Which photoreceptor family primarily mediates this response in plants?
(A) Phototropins
(B) Phytochromes
(C) Cryptochromes
(D) UV-B resistance locus 8 (UVR8)

2014

165. During plant cell wall expansion, new structural material must be incorporated to prevent wall thinning. Which mechanism primarily delivers

(A) Superoxide anion ($O_2^{\cdot -}$)
(B) Hydroxyl radical ($OH^{\cdot}$)
(C) Singlet oxygen ($^1O_2$)
(D) Hydrogen peroxide (H_2O_2)

2014

208. The ascorbate-glutathione cycle strictly localizes to chloroplasts and other compartments. What is its primary function?
(A) Scavenging hydrogen peroxide to prevent oxidative damage
(B) Synthesis of vitamin C
(C) Fixing carbon dioxide during severe drought
(D) Production of heat shock proteins

2017

209. Cold acclimation is the process by which plants increase their freezing tolerance after exposure to low, non-freezing temperatures. This process is centrally mediated by the transcriptional activation of which gene family?
(A) COR (Cold-Regulated) genes via CBF/DREB transcription factors
(B) PR (Pathogenesis-Related) genes via NPR1
(C) NIF (Nitrogen Fixation) genes via NifA
(D) EXP (Expansin) genes

2006

210. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Proline accumulation is a widespread biochemical marker of water deficit and salinity stress in plants.
Reason (R) : Proline acts strictly as a structural component of cell walls to prevent physical collapse during plasmolysis.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2018

211. Which primary organelle is considered the major site of ROS generation under light-induced abiotic stress (photooxidative stress)?
(A) Chloroplast
(B) Vacuole
(C) Endoplasmic reticulum
(D) Golgi apparatus

2014

212. To protect membrane fluidity during cold stress, what biochemical modification occurs in membrane lipids?
(A) Increase in the degree of unsaturation of fatty acids
(B) Complete replacement of phospholipids with triglycerides
(C) Saturation of all fatty acid tails
(D) Cleavage of lipid heads by phospholipase C

2013

213. Heavy metal toxicity (e.g., cadmium) induces the synthesis of phytochelatins. These peptides are synthesized enzymatically from which precursor molecule?
(A) Glutathione
(B) S-adenosylmethionine
(C) Proline
(D) Metallothionein

NODIA

2014

214. Which enzyme catalyzes the disproportionation of hydrogen peroxide into water and oxygen, primarily functioning in peroxisomes?
(A) Catalase
(B) Peroxidase
(C) Superoxide dismutase
(D) Ascorbate peroxidase

2019

215. Identify the INCORRECT statement regarding heat shock proteins (HSPs) in plant abiotic stress response.
(A) Their expression is strictly induced only at temperatures above 45°C.
(B) They primarily function as molecular chaperones to prevent protein aggregation.
(C) They assist in refolding heat-denatured proteins.
(D) They are classified by their molecular weight (e.g., HSP70, HSP90).

2008

216. Which signaling molecule plays an upstream role as a secondary messenger linking the perception of abiotic stress to the activation of stress-responsive kinases and gene expression?
(A) Cytosolic calcium (Ca^{2+})
(B) Gibberellic acid
(C) Starch
(D) Cellulose synthase

(A) Homogalacturonan (HG)
(B) Rhamnogalacturonan II (RG-II)
(C) Xyloglucan
(D) Arabinoxylan

2006

237. The charge and properties of homogalacturonan (HG) depend heavily on the activity of pectin methylesterases (PMEs). What do PMEs do to HG?
(A) They remove methyl groups, exposing carboxyl groups that can cross-link via calcium ions to form rigid gels.
(B) They add methyl groups to the galacturonic acid residues, preventing calcium cross-linking.
(C) They cleave the polymer backbone into small oligogalacturonides.
(D) They attach arabinose side chains.

2006

238. Fructans are water-soluble polysaccharides used by some plants as alternative carbon reserves. Where are fructans typically synthesized and stored?
(A) Central vacuole
(B) Amyloplasts
(C) Chloroplasts
(D) Cell wall

2012

239. Which enzyme is responsible for the cleavage of sucrose into fructose and UDP-glucose, playing a vital role in providing substrates for cell wall synthesis in sink tissues?
(A) Sucrose synthase
(B) Acid invertase
(C) Amylase
(D) Phosphoglucomutase

2002

240. Select the correct sequence of intermediates in the cytosolic synthesis of sucrose from triose phosphates.
(A) Fructose-1,6-bisphosphate → Fructose-6-phosphate → Sucrose-6-phosphate → Sucrose
(B) Glucose-1-phosphate → UDP-glucose → Sucrose
(C) Triose phosphate → ADP-glucose → Amylose → Sucrose
(D) Fructose-6-phosphate → Glucose-6-phosphate → Fructose → Sucrose

2019

241. Cyanogenic glycosides are defensive secondary metabolites that release toxic hydrogen cyanide (HCN) upon tissue damage. This toxic release process is termed:
(A) Cyanogenesis
(B) Hydrolysis
(C) Saponification
(D) Glucosinolation

2008

242. The structural backbone of cyanogenic glycosides is derived entirely from which class of primary metabolites?
(A) Amino acids
(B) Carbohydrates
(C) Fatty acids
(D) Terpenoids

2003

243. In intact plant tissues, how does the plant prevent autotoxicity from its own cyanogenic glycosides?
(A) By physically separating the glycosides from their degradative enzymes
(B) By keeping the local pH exceptionally high
(C) By continually synthesizing an antidote protein
(D) By strictly storing the cyanide gas in specialized cells

2019

244. The release of HCN from a cyanogenic glycoside is a two-step enzymatic process. Which two enzymes sequentially catalyze this breakdown?
(A) Beta-glucosidase and Hydroxynitrile lyase
(B) Myrosinase and Sulfatase
(C) Lipoxygenase and Hydroperoxide lyase
(D) Cellulase and Pectinase

2015

245. Cassava is a crucial staple crop that contains significant amounts of cyanogenic glycosides. What are the two primary cyanogenic glycosides found in cassava?
(A) Linamarin and Lotaustralin
(B) Amygdalin and Prunasin
(C) Dhurrin and Taxiphyllin
(D) Sinigrin and Glucobrassicin

2022

246. What is the immediate physiological mechanism by which released hydrogen cyanide (HCN) causes toxicity to herbivores and humans?
(A) It potently inhibits cytochrome c oxidase in the mitochondrial electron transport chain.
(B) It drastically lowers blood pH.

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2014

226. What role do reactive oxygen species (ROS) play specifically during the hypersensitive response, apart from direct toxicity to the pathogen?
(A) Signaling molecules and wall cross-linking agents.
(B) Suppressors of PR genes to prevent autoimmunity.
(C) Metabolic precursors for salicylic acid synthesis.
(D) Transporters of nutrients to the infection site.

2018

227. Phytoanticipins differ fundamentally from phytoalexins in plant defense. What is this primary difference?
(A) Phytoanticipins are pre-formed inhibitory compounds present before infection, whereas phytoalexins are synthesized de novo post-infection.
(B) Phytoanticipins are strictly proteins, whereas phytoalexins are organic compounds.
(C) Phytoanticipins defend against viruses, while phytoalexins defend against fungi.
(D) Phytoanticipins act systemically, while phytoalexins act locally.

2010

228. Upon chewing by a caterpillar, systemic signaling induces defense in undamaged leaves. Which peptide hormone is recognized as a major systemic mobile signal linking wounding to jasmonic acid synthesis?
(A) Systemin
(B) Florigen (FT)
(C) CLAVATA3
(D) Phytosulfokine

2016

229. Plant starch consists of two types of glucose polymers. Which of the following accurately describes the structure of amylopectin?
(A) A highly branched polymer of alpha-1,4 linked glucose with alpha-1,6 branch points
(B) An unbranched, linear polymer of alpha-1,4 linked glucose
(C) A linear polymer of beta-1,4 linked glucose
(D) A branched polymer of beta-1,3 linked glucose

2024

230. Where is starch primarily synthesized and transiently stored during the day in a photosynthetic leaf cell?
(A) Chloroplast stroma
(B) Cytosol
(C) Vacuole
(D) Mitochondria

2024

231. The biosynthesis of starch requires an activated glucose donor. Which nucleotide sugar is specifically utilized by starch synthase in the plastid?
(A) ADP-glucose
(B) UDP-glucose
(C) GDP-glucose
(D) CDP-glucose

2002

232. Cellulose, the principal structural component of plant cell walls, is a linear polymer of which monomer linked by which type of bond?
(A) Beta-D-glucose, beta-1,4 linkages
(B) Alpha-D-glucose, beta-1,4 linkages
(C) Beta-D-glucose, alpha-1,4 linkages
(D) Alpha-D-galactose, beta-1,3 linkages

NODIA

2001

233. Unlike starch synthesis in the plastid, where does the synthesis of cellulose strictly occur?
(A) At the plasma membrane by the Cellulose Synthase Complex (CSC)
(B) Within the Golgi apparatus
(C) In the rough endoplasmic reticulum
(D) In the apoplast by registered enzymes

2007

234. Sucrose is the primary transport sugar in most plants. It is a non-reducing disaccharide composed of which two monosaccharides?
(A) Glucose and Fructose
(B) Glucose and Galactose
(C) Two molecules of Glucose
(D) Fructose and Galactose

2007

235. The synthesis of sucrose in the cytosol is tightly regulated. Which enzyme catalyzes the irreversible synthesis of sucrose-6-phosphate, representing a key control point?
(A) Sucrose-phosphate synthase (SPS)
(B) Sucrose synthase
(C) Invertase
(D) UDP-glucose pyrophosphorylase

2008

236. Pectins are highly complex, hydrophilic polysaccharides characteristic of the middle lamella and primary cell wall. What is the most abundant pectic polymer?

receptors spanning the endoplasmic reticulum or plasma membrane?
(A) Histidine kinases (e.g., AHKs)
(B) Serine/threonine kinases
(C) G-protein coupled receptors
(D) Tyrosine kinases

2015

198. In the cytokinin two-component signaling system, what protein family translocates to the nucleus to regulate gene expression after receiving a phosphoryl group from histidine phosphotransfer proteins (AHPs)?
(A) Type-B ARRs (Arabidopsis Response Regulators)
(B) ARFs (Auxin Response Factors)
(C) ERFs (Ethylene Response Factors)
(D) PIFs (Phytochrome Interacting Factors)

2005

199. Identify the receptor complex strictly required for the perception of jasmonic acid-isoleucine (JA-Ile) to trigger the degradation of JAZ repressors.
(A) COI1-JAZ
(B) TIR1-Aux/IAA
(C) GID1-DELLA
(D) PYR/PYL/RCAR-PP2C

2009

200. Ethylene receptors (e.g., ETR1) function in a manner contrary to typical hormone receptors. How do they regulate the downstream signaling kinase CTR1?
(A) Receptors activate CTR1 to suppress the response.
(B) Ethylene activates receptors to stimulate CTR1.
(C) Binding causes the receptor to destroy CTR1.
(D) The receptor requires CTR1 to bind ethylene gas.

2010

201. The key transcriptional master regulators that act downstream of the ethylene signaling cascade to trigger fruit ripening and senescence are known as:
(A) EIN3 and EIL1 transcription factors
(B) ARF transcription factors
(C) MYB transcription factors
(D) Type-A ARRs

2023

202. The core abscisic acid (ABA) signaling pathway involves a double-negative regulatory mechanism. Which class of enzymes act as negative regulators (repressors) that are inhibited when ABA binds to its receptors?
(A) Protein Phosphatases type 2C (PP2Cs).
(B) SnRK2 signaling kinases.
(C) Mitogen-activated protein kinases (MAPKs).
(D) Calcium-dependent protein kinases (CDPKs).

2003

203. Upon release from PP2C inhibition, which kinases become active to phosphorylate downstream targets like ABF transcription factors and guard cell ion channels?
(A) SnRK2 kinases
(B) CDKA kinases
(C) Histidine kinases
(D) Receptor-like kinases (RLKs)

2022

204. Brassinosteroid signaling uniquely involves a plasma membrane receptor kinase (BRI1). What is the ultimate downstream effect of BRI1 activation in the nucleus?
(A) Dephosphorylation and nuclear accumulation of the transcription factors BES1 and BZR1
(B) Degradation of the repressor DELLA
(C) Phosphorylation and activation of JAZ proteins
(D) Cleavage of EIN2

2024

205. In response to severe osmotic stress (drought or salinity), plants universally accumulate specific low-molecular-weight organic compounds to lower water potential without disrupting cellular metabolism. These are known as:
(A) Osmoprotectants (Compatible solutes)
(B) Phytochelatins
(C) Phytoalexins
(D) Alkaloids

2023

206. Which of the following compounds is a quintessential compatible solute widely synthesized in crop plants like wheat and spinach during abiotic stress?
(A) Glycine betaine
(B) Hydrogen peroxide
(C) Lignin
(D) Tannin

2023

207. Abiotic stresses often trigger the overproduction of Reactive Oxygen Species (ROS). Which primary radical is detoxified by the enzyme Superoxide Dismutase (SOD)?

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(C) It cleaves hemoglobin into individual subunits.
(D) It degrades neural myelin sheaths.

2016

247. Dhurrin is a cyanogenic glycoside highly accumulated in young sorghum seedlings. Which amino acid serves as the direct biosynthetic precursor to dhurrin?
(A) Tyrosine
(B) Valine
(C) Phenylalanine
(D) Isoleucine

2008

248. The biosynthesis of cyanogenic glycosides involves the sequential action of two closely linked cytochromes P450. What intermediate is formed by the first P450 acting on the precursor amino acid?
(A) An oxime
(B) A nitrile
(C) An alpha-hydroxynitrile
(D) A glucosinolate

2010

249. Which statement INCORRECTLY characterizes the defensive role of cyanogenic glycosides?
(A) HCN acts as an attractant for pollinating insects.
(B) They act primarily as a deterrent against generalist herbivores.
(C) Certain specialized insects can sequester plant cyanogenic glycosides for their own defense.
(D) Crushing or chewing the plant tissue is usually required to trigger cyanide release.

2024

250. Arrange the following intermediates in the correct sequential order for the biosynthesis of cyanogenic glycosides:
I. Alpha-hydroxynitrile
II. Cyanogenic glycoside
III. Amino acid
IV. Aldoxime
Which of the following is the correct order?
(A) III, I, IV, II
(B) III, IV, I, II
(C) IV, III, I, II
(D) I, III, IV, II

2015

251. Which enzyme catalyzes the final step in the biosynthesis of a cyanogenic glycoside by adding a sugar moiety to stabilize the reactive aglycone?
(A) UDP-glucosyltransferase (UGT)
(B) Cytochrome P450 CYP71
(C) Hydroxynitrile lyase
(D) Beta-glucosidase

NODIA

2016

252. Amygdalin is a well-known cyanogenic glycoside found abundantly in the seeds of which plant family?
(A) Rosaceae
(B) Brassicaceae
(C) Solanaceae
(D) Poaceae

2019

253. Glucosinolates are sulfur- and nitrogen-containing secondary metabolites primarily associated with which plant order?
(A) Brassicales
(B) Rosales
(C) Fabales
(D) Solanales

2018

254. The core structure of a glucosinolate contains which specific chemical linkages?
(A) A beta-D-thioglucose group, a sulfonated oxime, and an amino acid-derived side chain
(B) An alpha-D-glucose group attached to a cyanide ion
(C) A cyclic terpene bound to an ester linkage
(D) A polyamine bound to a fatty acid

2010

255. Similar to the cyanogenic glycoside system, glucosinolates require spatial separation from their degrading enzyme. What is the classic name of the endogenous enzyme that hydrolyzes glucosinolates upon tissue damage?
(A) Myrosinase (Thioglucosidase)
(B) Lipase
(C) Amylase
(D) Alliinase

2001

256. Upon hydrolysis by myrosinase, the unstable aglycone intermediate spontaneously rearranges. Which highly reactive, pungent compound is the most common predominant product?
(A) Isothiocyanate
(B) Hydrogen cyanide
(C) Allicin
(D) Indole-3-acetic acid

ANSWERS

1. (A) The plant cannot complete its life cycle in its absence.
Essentiality for plant nutrients requires that a plant is unable to complete its vegetative or reproductive stages in the absence of the specific element. This criterion emphasizes that the nutrient is indispensable for the life cycle. Furthermore, the element's role must be specific, meaning it cannot be replaced by any other mineral element present in the environment.

2. (C) Zinc
Zinc is an essential micronutrient involved in diverse physiological processes. It serves as a structural component for several enzymes, including carbonic anhydrase and alcohol dehydrogenase. Crucially, zinc is required for maintaining the structural integrity of ribosomes and the synthesis of proteins, making it vital for cellular growth and developmental regulation in all higher plants during their life cycle.

3. (A) Cofactor for nitrate reductase and nitrogenase.
Molybdenum is an essential micronutrient that plays a critical role in nitrogen metabolism. It functions as a metallic cofactor for key enzymes such as nitrate reductase, which reduces nitrate to nitrite, and nitrogenase, which fixes atmospheric nitrogen. Without molybdenum, plants cannot effectively assimilate nitrogen, leading to stunted growth and severe nitrogen deficiency symptoms despite having adequate soil nitrogen.

4. (D) Iron is required in large quantities as a central atom of chlorophyll.
Iron is classified as a micronutrient because plants require it in relatively small quantities compared to elements like nitrogen or potassium. While iron is essential for chlorophyll biosynthesis and is a component of cytochromes, the central atom of the chlorophyll molecule is actually magnesium. Magnesium is a macronutrient that forms the core of the porphyrin ring structure.

5. (B) Magnesium
Magnesium is a highly mobile macronutrient within the plant's vascular system. When soil availability is low, the plant translocates magnesium from older tissues to actively growing younger leaves. Consequently, deficiency symptoms like interveinal chlorosis, where the area between veins turns yellow while veins remain green, appear first in the older, more mature foliage rather than the newer growth.

6. (C) Molybdenum
Molybdenum deficiency specifically impacts members of the Brassicaceae family, such as cauliflower and broccoli. The condition known as whiptail occurs because molybdenum is required for nitrogen assimilation. Its absence causes the leaf blades to become severely restricted and distorted, leaving only the midrib and small fragments of leaf tissue, resembling the thin lash of a whip in appearance.

7. (D) Nitrogen and Sulfur
Nitrogen and sulfur are fundamental building blocks of structural organic molecules within plants. Nitrogen is a primary component of amino acids, proteins, and nucleic acids like DNA and RNA. Sulfur is essential for the synthesis of specific amino acids, such as cysteine and methionine, which are crucial for forming the tertiary structure of proteins through stable disulfide bridges.

8. (A) Structural component of the enzyme urease
Nickel was identified as an essential micronutrient due to its specific role as a structural component of the enzyme urease. This enzyme catalyzes the hydrolysis of urea into ammonia and carbon dioxide. In the absence of nickel, urea accumulates to toxic levels in leaf tips, causing necrosis, particularly in plants that utilize ureides for long-distance nitrogen transport.

9. (B) Calcium
Calcium is characterized as a highly immobile nutrient within the plant once it is incorporated into structural components. Unlike mobile elements that can be redistributed from older to younger tissues, calcium remains fixed in cell walls. Therefore, deficiency symptoms always manifest first at the growing tips and young leaves, showing as distorted growth, hooked leaf tips, or localized necrosis.

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germination.

2009

268. The completion of germination is visibly marked by which definitive event?
(A) The radicle protrudes through the seed coat/ endosperm.
(B) The seed swells to twice its volume.
(C) Alpha-amylase is first secreted.
(D) The cotyledons turn green and begin photosynthesis.

2010

269. What force primarily drives the expansion of radicle cells leading to their protrusion during Phase III of germination?
(A) Increase in turgor pressure driven by osmotically active solute generation
(B) Transpiration pull
(C) Sudden increase in cell division
(D) Tension from the expanding seed coat

2005

270. Many seeds require specific environmental cues to initiate germination. Which photoreceptor mediates the promotion of germination by red light?
(A) Phytochrome
(B) Phototropin
(C) Cryptochrome
(D) UVR8

2012

271. In seeds requiring light for germination, exposure to far-red light has what effect?
(A) It reverses the effect of red light and inhibits germination by converting Pfr back to Pr.
(B) It maximally stimulates germination.
(C) It converts Pr to Pfr, accelerating imbibition.
(D) It degrades the seed coat.

2022

272. Stratification is an agricultural technique used to break seed dormancy. It artificially mimics which natural environmental condition?
(A) A period of moist, cold conditions
(B) Prolonged drought
(C) Exposure to intense light
(D) Scarification by physical abrasion

2010

273. Prior to the full reactivation of mitochondrial oxidative phosphorylation during early imbibition, how does the seed generate its initial ATP?
(A) Glycolysis and fermentation
(B) Photosynthesis
(C) Gluconeogenesis
(D) Beta-oxidation

NODIA

2016

274. In epigeal germination, which structure elongates rapidly to pull the cotyledons above the soil surface?
(A) Hypocotyl
(B) Epicotyl
(C) Radicle
(D) Coleoptile

2001

275. In hypogeal germination, the cotyledons remain below ground. Which part of the seedling axis elongates to propel the shoot out of the soil?
(A) Epicotyl (or mesocotyl in cereals)
(B) Hypocotyl
(C) Primary root
(D) Suspensor

2013

276. Identify the primary function of the aleurone layer in cereal grains during germination.
(A) It synthesizes and secretes hydrolytic enzymes into the starchy endosperm.
(B) It serves as the primary starch storage tissue.
(C) It is the protective dead tissue forming the husk.
(D) It absorbs water from the soil directly into the embryo.

2009

277. The mobilization of carbohydrate reserves in the cereal endosperm heavily relies on alpha-amylase. What is the specific biochemical action of this enzyme?
(A) Random endo-cleavage of alpha-1,4 glycosidic bonds in amylose and amylopectin
(B) Cleavage of beta-1,4 glycosidic bonds in cellulose
(C) Exo-cleavage of maltose units from the non-reducing ends of starch
(D) Hydrolysis of alpha-1,6 branch points

2022

278. Oilseed crops store lipids as their primary reserve. These triglycerides are broken down into fatty acids by which enzyme?
(A) Lipase
(B) Protease
(C) Lipoxygenase
(D) Isocitrate lyase

19. (A) By secreting phytosiderophores to chelate Fe^{3+} (Strategy II)
In calcareous soils with high pH, iron becomes highly insoluble. Graminaceous plants utilize Strategy II, involving the secretion of phytosiderophores. These organic compounds are high-affinity chemical binders that trap Fe3+ in the rhizosphere. The resulting ferric-phytosiderophore complex is then specifically recognized and taken up by specialized transporters located on the root cell membrane to overcome the limited iron availability.

20. (D) P-III, Q-I, R-IV, S-II
Ion transport mechanisms are classified by the direction and nature of solute movement across membranes.
Mechanism Classifications:
1. Uniport facilitates the movement of a single ion species down its gradient.
2. Symport involves the simultaneous transport of two different substances in the same direction.
3. Antiport moves two substances in opposite directions.
4. Aquaporins are specialized channels for passive water movement.

21. (B) The root cortex apoplast accessible via diffusion.
The apparent free space refers to the volume of the root tissue that is readily accessible to external ions by simple diffusion. This space consists of the apoplast, including the cell walls and intercellular spaces of the root cortex. It represents the non-selective portion of the root where ions move freely before reaching the selective barrier of the endodermis.

22. (C) Low-affinity, high-capacity transport systems
The dual isotherm model describes ion uptake rates across varying external concentrations. Mechanism II operates at high external concentrations and is characterized by low-affinity, high-capacity transport. Unlike the high-affinity systems that saturate at low concentrations, this mechanism allows for a linear or near-linear increase in ion uptake as the availability of nutrients in the soil solution increases significantly.

23. (A) It blocks apoplastic movement of water and ions.
The Casparian strip is a band of suberin and lignin located in the radial and transverse walls of the endodermal cells. Its primary function is to block the apoplastic movement of water and dissolved minerals into the stele. This force forces all substances to cross the plasma membrane of endodermal cells, providing a selective checkpoint for nutrient entry.

24. (D) Hypoxia or treatment with respiratory inhibitors
Active ion uptake is a metabolically demanding process that relies on a constant supply of ATP generated through aerobic respiration. Environmental conditions that limit oxygen availability, such as waterlogging or hypoxia, drastically inhibit respiration. Similarly, metabolic inhibitors that block the respiratory chain prevent ATP production, leading to a profound decrease in the active transport of nutrients in roots.

25. (C) Incorporation into glutamate to form glutamine
High concentrations of ammonia are toxic to plant cells because they dissipate proton gradients across membranes. To prevent damage, plants rapidly assimilate ammonia into organic molecules. The primary detoxification pathway involves the enzyme glutamine synthetase, which incorporates ammonia into glutamate to form glutamine. This process ensures that nitrogen is stored in a stable, non-toxic, and mobile organic form.

26. (C) Sulfur deficiency – Reduced synthesis of amino acids
Sulfur is a fundamental component of the amino acids cysteine and methionine. A deficiency in sulfur directly disrupts the protein synthesis pathway because these essential building blocks cannot be produced in sufficient quantities. This leads to a general reduction in protein content and overall plant growth, manifesting as chlorosis in young leaves due to impaired structural and functional development.

27. (A) Glutamate
The GS-GOGAT cycle is the primary pathway for nitrogen assimilation in plants. Glutamine synthetase first incorporates ammonia into glutamate to form glutamine. Subsequently,

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(A) Gibberellic acid (GA)
(B) Cytokinin
(C) Salicylic acid
(D) Jasmonic acid

2016

291. During seed imbibition, what typically happens to the endogenous levels of ABA?
(A) They rapidly decrease due to both leaching and active enzymatic catabolism.
(B) They remain constantly high until the radicle emerges.
(C) They rapidly increase to prevent premature germination.
(D) They are converted directly into gibberellins.

2017

292. Which enzyme is a key regulator of ABA catabolism, actively degrading ABA during the breaking of seed dormancy?
(A) ABA 8'-hydroxylase
(B) Nine-cis-epoxycarotenoid dioxygenase (NCED)
(C) GA 20-oxidase
(D) ACC synthase

2007

293. The synthesis of active gibberellins spikes prior to radicle emergence. Which enzyme's up-regulation is crucial for this de novo GA biosynthesis?
(A) GA 3-oxidase
(B) GA 2-oxidase
(C) Zeaxanthin epoxidase
(D) Phytoene synthase

2016

294. Mutants deficient in ABA biosynthesis exhibit a phenomenon where seeds germinate precociously while still attached to the mother plant. What is this phenomenon called?
(A) Vivipary
(B) Apomixis
(C) Parthenocarpy
(D) Stratification

2005

295. Seed dormancy enforced by physical barriers is known as:
(A) Physical dormancy
(B) Physiological dormancy
(C) Morphological dormancy
(D) Secondary dormancy

2023

296. Secondary dormancy is an adaptive trait. How is it induced in mature, non-dormant seeds?
(A) By exposure to unfavorable environmental conditions post-dispersal
(B) By completing the maturation process on the mother plant
(C) By exposure to favorable germination conditions for extended periods
(D) By strictly treating the seeds with gibberellic acid

2012

297. How does the transcription factor ABI3 function in the context of seed dormancy?
(A) It acts as a key positive regulator in the ABA signaling network to enforce dormancy.
(B) It represses ABA signaling and promotes GA signaling, breaking dormancy.
(C) It acts strictly downstream of GA to induce alpha-amylase.
(D) It degrades seed storage proteins.

2004

298. Light promotes germination in certain seeds by shifting the hormonal balance. Active phytochrome (Pfr) directly regulates the genes for hormone metabolism by:
(A) Decreasing ABA synthesis and increasing GA synthesis
(B) Increasing ABA synthesis and decreasing GA synthesis
(C) Degrading both ABA and GA equally
(D) Converting ABA directly into gibberellic acid

2019

299. In endospermic seeds, radicle protrusion requires the physical weakening of the endosperm layer surrounding the radicle tip. Which hormone strictly promotes the secretion of cell-wall-remodeling enzymes to accomplish this?
(A) GA
(B) ABA
(C) Jasmonate
(D) Salicylic acid

2017

300. The DELAY OF GERMINATION 1 (DOG1) protein is a master regulator of seed dormancy. Its accumulation in seeds tightly correlates with:
(A) The depth of primary dormancy established during seed maturation
(B) Rapid vivipary
(C) High levels of alpha-amylase
(D) Immediate sensitivity to red light upon shedding

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reductive assimilation of nitrate into ammonia and the reduction of sulfate during the synthesis of sulfur compounds.

37. (A) Plastids
In higher plants, the assimilation of sulfate into organic sulfur compounds primarily occurs within the plastids, such as chloroplasts in leaves or proplastids in roots. This compartment contains the full suite of enzymes required for sulfate activation and its subsequent reduction to sulfide. The process is tightly integrated with photosynthesis, which provides the necessary energy and reducing equivalents for these steps.

38. (C) ATP sulfurylase
Before sulfate can be reduced, it must be chemically activated due to its high stability. This initial step is catalyzed by the enzyme ATP sulfurylase. The enzyme uses ATP to convert inorganic sulfate into adenosine 5'-phosphosulfate. This activation step is essential because it raises the energy level of the sulfate group, making it susceptible to subsequent reductive reactions in the plastid.

39. (A) Adenosine 5'-phosphosulfate (APS)
The action of ATP sulfurylase on inorganic sulfate results in the formation of adenosine 5'-phosphosulfate. This molecule is the immediate product of the activation reaction and serves as the branch point for further sulfur metabolism. APS can be further phosphorylated for sulfation reactions or reduced by APS reductase to initiate the pathway toward cysteine and other organic sulfur compounds.

40. (A) I, II and IV
The sulfate assimilation pathway involves a series of coordinated enzymatic reductions located primarily within the plastids.
Key Steps:
P. APS reductase reduces APS to sulfite using reduced glutathione as an electron donor.
Q. Sulfite reductase then converts sulfite to sulfide using ferredoxin.
R. Cysteine is the first stable organic sulfur compound formed, serving as a precursor for methionine.

41. (A) It provides the carbon skeleton for the incorporation of sulfide to form cysteine.
O-acetylserine plays a pivotal role in sulfur metabolism by providing the carbon skeleton required for the incorporation of sulfide. It is synthesized from serine and acetyl-CoA. The enzyme O-acetylserine (thiol) lyase then catalyzes the reaction between OAS and sulfide to produce cysteine. Additionally, OAS acts as a signaling molecule to regulate the expression of sulfate transporters and assimilation enzymes.

42. (C) Serine acetyltransferase and O-acetylserine(thiol)lyase
The final steps of cysteine biosynthesis are catalyzed by a multienzyme complex called the cysteine synthase complex. This complex consists of serine acetyltransferase, which produces O-acetylserine, and O-acetylserine (thiol) lyase, which incorporates sulfide into the carbon skeleton. This coordinated action ensures the efficient conversion of inorganic sulfide into the organic amino acid cysteine while preventing the accumulation of toxic metabolic intermediates.

43. (A) Aspartate
The biosynthesis of methionine is closely linked to the aspartate family of amino acids. The carbon skeleton for methionine is ultimately derived from aspartate through a series of metabolic intermediates, including homoserine. Sulfur is later incorporated from cysteine via the formation of cystathionine. This complex pathway integrates both nitrogen and sulfur metabolism to produce an essential amino acid required for proteins.

44. (D) Cystathionine
Cystathionine is the critical intermediate that bridges the biosynthetic pathways of cysteine and methionine. In plants, the sulfur from cysteine is transferred to a four-carbon skeleton derived from homoserine to form cystathionine. This molecule is then cleaved by cystathionine beta-lyase to produce homocysteine, which is subsequently methylated to form methionine, the final product of the sulfur assimilation pathway in plants.

45. (C) Feedback inhibition of ATP sulfurylase by accumulated thiols
The sulfate assimilation pathway is highly regulated to match the plant's demand for organic sulfur. A key regulatory mechanism involves feedback inhibition, where high internal concentrations of thiols, such as cysteine and glutathione, inhibit the activity of the first committed enzyme, ATP sulfurylase. This

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10. (D) A is false but R is true.
Silicon is not classified as an essential element for all higher plants according to standard criteria, as most can complete their life cycle without it. However, it is considered a beneficial element, particularly for grasses and sedges. It provides structural strength to cell walls and improves resistance against pests, diseases, and various environmental abiotic stress factors like lodging.

11. (A) Calcium
Calcium serves as a vital structural component in the plant cell wall, specifically within the middle lamella. It acts as a divalent cation that bridges the carboxyl groups of pectic acid chains, forming calcium pectate. This chemical bonding provides mechanical strength and adhesion between adjacent cells, which is essential for maintaining the overall structural integrity of plant tissues.

12. (C) Boron
Boron is a micronutrient that plays a unique role in reproductive development. It is essential for the germination of pollen grains and the subsequent elongation of the pollen tube through the style. Boron facilitates the transport of sugars and is involved in cell wall synthesis, ensuring that the male gametophyte effectively reaches the ovule for successful fertilization during reproduction.

13. (D) Movement against a gradient using ATP hydrolysis.
Active transport is the movement of mineral ions across a cell membrane against their electrochemical or concentration gradient. This physiological process is highly selective and requires the expenditure of metabolic energy, typically derived from ATP hydrolysis. Specialized carrier proteins or pumps facilitate this movement, allowing plants to accumulate essential nutrients even when soil concentrations are extremely low in the rhizosphere.

14. (C) Primary uses ATP directly, while secondary uses electrochemical gradients.
Primary active transport involves the direct use of metabolic energy, such as ATP, to move ions across membranes via pumps. In contrast, secondary active transport relies on the electrochemical gradient established by primary pumps. It utilizes the energy stored in these gradients to co-transport other solutes against their own concentration gradients through specific symporter or antiporter membrane proteins.

15. (B) Saturation kinetics at high external ion concentrations
The carrier-mediated model of ion uptake suggests that specialized membrane proteins bind specific ions for transport. Evidence for this is provided by saturation kinetics, where the rate of ion uptake increases with external concentration only up to a point. Once all available carrier sites are occupied, the transport rate reaches a maximum, mirroring the characteristic behavior of enzyme-substrate interactions.

16. (D) They transport ions exclusively via active transport against gradients.
Ion channels are specialized integral membrane proteins that form hydrophilic pores for the rapid, passive movement of ions. They do not perform active transport against electrochemical gradients; instead, they allow ions to flow down their established gradients. These channels are highly regulated and can be gated by factors like membrane voltage, specific ligands, or various mechanical stimuli during signaling.

17. (A) Extruding protons to the apoplast to establish an electrochemical gradient
The plasma membrane H+-ATPase acts as a primary active transporter by using ATP to pump protons out of the cytoplasm into the apoplast. This action generates a significant electrochemical proton gradient and a negative membrane potential. These gradients provide the necessary driving force for the secondary active transport of various cations, anions, and neutral solutes into the plant cell.

18. (C) Proton-anion symporters
Nitrate ions are negatively charged and must often be taken up against a steep electrical gradient across the plasma membrane. Plants utilize proton-anion symporters to achieve this. These transporters couple the energetically favorable inward movement of protons, driven by the H+-ATPase gradient, with the inward movement of nitrate, ensuring efficient nutrient acquisition from the soil solution despite the repulsion.

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2009

257. The type of hydrolysis product formed from a glucosinolate heavily depends on the presence of specific specifier proteins. Under what condition does the formation of nitriles typically occur?
(A) Highly acidic pH and presence of ESP
(B) Alkaline pH and presence of Epithiospecifier Protein (ESP)
(C) Complete absence of myrosinase
(D) Elevated temperatures strictly above 60°C

2006

258. Glucosinolates are synthesized from amino acids. Which amino acid is the primary precursor for aliphatic glucosinolates in Arabidopsis and broccoli?
(A) Methionine
(B) Tryptophan
(C) Phenylalanine
(D) Tyrosine

2014

259. Indolic glucosinolates are derived from which amino acid?
(A) Tryptophan
(B) Methionine
(C) Alanine
(D) Glutamine

2014

260. The breakdown of indolic glucosinolates can yield biologically active molecules that influence plant growth. Which common plant hormone can ultimately be derived from the degradation of specific indolic glucosinolates?
(A) Indole-3-acetic acid (Auxin)
(B) Gibberellic acid
(C) Abscisic acid
(D) Salicylic acid

2004

261. Which specialized plant cells are documented as the primary storage sites for myrosinase, isolating it from the vacuolar glucosinolates located in adjacent cells?
(A) Idioblasts or Myrosin cells
(B) Guard cells
(C) Trichomes
(D) Sieve tube elements

2018

262. Identify the INCORRECT statement regarding the ecological role of the "mustard oil bomb" (glucosinolate-myrosinase system).
(A) The system relies on light-induced activation of myrosinase rather than tissue damage.
(B) It serves as a potent deterrent against generalist herbivores.
(C) Certain specialist herbivores have evolved detoxification mechanisms.
(D) Isothiocyanates possess strong antimicrobial and fungicidal properties.

2017

263. Sulforaphane is an isothiocyanate derived from the hydrolysis of which specific glucosinolate found in broccoli?
(A) Glucoraphanin
(B) Sinigrin
(C) Glucobrassicin
(D) Progoitrin

2023

264. Canola oil is derived from rapeseed varieties that have been bred to reduce the levels of which compounds?
(A) Erucic acid and Glucosinolates
(B) Cyanogenic glycosides and Tannins
(C) Alkaloids and Phytic acid
(D) Gossypol and Saponins

2012

265. Seed germination strictly begins with which fundamental physical process?
(A) Imbibition (uptake of water)
(B) Transcription of alpha-amylase
(C) Emergence of the radicle
(D) Cellular division in the shoot apex

2004

266. Imbibition follows a characteristic triphasic curve. What accurately describes Phase I of water uptake?
(A) Passive water uptake driven by seed matric potential.
(B) Slow, strictly metabolism-dependent water uptake.
(C) A plateau phase where water uptake temporarily halts.
(D) Rapid uptake driven entirely by vacuolar expansion.

2024

267. During Phase II of imbibition (the lag phase), which major physiological event occurs?
(A) Active cellular metabolism, DNA repair, and mitochondrial reorganization commence.
(B) The radicle physically penetrates the seed coat.
(C) Matric potential continues to pull water rapidly into the seed.
(D) The seed dehydrates to prepare for

NODIA

glutamate synthase transfers the amide group from glutamine to alpha-ketoglutarate, producing two molecules of glutamate. Although glutamine is an intermediate, glutamate is considered the primary initial stable product that provides nitrogen for other transamination reactions.

28. (A) Glutamine synthetase and Glutamate synthase
Glutamine synthetase and glutamate synthase are the two enzymes that function together in the GS-GOGAT cycle. This pathway is responsible for the vast majority of ammonia assimilation in higher plants. Glutamine synthetase captures inorganic nitrogen by forming glutamine, while glutamate synthase recycles the carbon skeletons to maintain the flow of nitrogen into various metabolic pathways and amino acids.

29. (A) Assimilating nitrate requires more reducing power than assimilating ammonia.
Nitrate assimilation is more energy-intensive than ammonia assimilation because nitrate must first be reduced. The conversion of nitrate to ammonia requires eight electrons, typically provided by NADH and reduced ferredoxin. In contrast, ammonia can be directly incorporated into amino acids. Therefore, plants utilizing nitrate as their primary nitrogen source expend significantly more reducing power and metabolic energy during the assimilation.

30. (B) II and III
Nitrogen assimilation is a regulated process that occurs in both roots and leaves depending on the species and environmental conditions. Light significantly enhances nitrate reduction in leaves by providing reduced ferredoxin through the photosynthetic electron transport chain. Once nitrogen is assimilated into organic forms, glutamine serves as a major mobile transport molecule that carries nitrogen through the vascular system.

31. (B) Pyrophosphate-dependent phospho fructokinase (PFP)
Under conditions of severe phosphorus deficiency, plants activate alternative metabolic pathways to conserve ATP and inorganic phosphate. A hallmark of this adaptation is the use of pyrophosphate-dependent phosphofructokinase instead of the ATP-dependent phosphofructokinase during glycolysis. This enzyme utilizes inorganic pyrophosphate as a phosphoryl donor, allowing the plant to maintain carbon flux while bypassing steps that require high ATP consumption.

32. (C) Nickel
Nickel is an essential micronutrient specifically required as a cofactor for the enzyme urease. This enzyme is responsible for the hydrolysis of urea into ammonia and carbon dioxide. Without sufficient nickel, plants cannot effectively process urea derived from internal metabolism or external fertilizers, leading to the accumulation of urea and localized toxic effects, particularly in the leaf tips.

33. (A) Sulfur
Phytochelatins are small peptides synthesized by plants to detoxify heavy metals through chelation and sequestration in the vacuole. These molecules are rich in thiol groups and are synthesized enzymatically from glutathione. Since glutathione is a sulfur-containing tripeptide, the availability of sulfur is directly required for the production of phytochelatins and the plant's overall tolerance to heavy metal toxicity.

34. (D) Blossom end rot in tomatoes
Blossom end rot is a physiological disorder in tomatoes and peppers caused by a localized deficiency of calcium in the developing fruit. Calcium is essential for cell wall stability and membrane integrity. When transpiration is low or calcium transport is insufficient to reach the rapidly growing distal end of the fruit, cell walls collapse and tissues die, resulting in lesions.

35. (B) Iron assimilation strictly occurs in the dark.
Iron is a vital component of electron transport chains in both mitochondria and chloroplasts, and its deficiency leads to interveinal chlorosis in young leaves. However, the statement that iron assimilation occurs strictly in the dark is incorrect. In fact, many iron uptake and reduction processes in leaves are stimulated by light or linked to photosynthetic activities and energy status.

36. (D) Provision of NADPH for reductive assimilation steps
The oxidative pentose phosphate pathway is a major metabolic route that generates NADPH in the cytosol and plastids. This NADPH serves as a critical source of reducing power for various biosynthetic and reductive processes. In mineral nutrition, it is specifically required for the

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2002

279. The conversion of stored lipid reserves into mobile sucrose is vital for the germinating oilseed. Where do the unique reactions of the glyoxylate cycle occur?
(A) Glyoxysomes
(B) Mitochondria
(C) Cytosol
(D) Chloroplasts

2024

280. Which two specific enzymes are unique to the glyoxylate cycle, allowing it to bypass the decarboxylation steps of the TCA cycle?
(A) Isocitrate lyase and Malate synthase
(B) Citrate synthase and Aconitase
(C) Malate dehydrogenase and Fumarase
(D) Succinate dehydrogenase and Alpha-ketoglutarate dehydrogenase

2013

281. In the glyoxylate cycle, isocitrate is cleaved into which two products?
(A) Glyoxylate and Succinate
(B) Malate and Acetyl-CoA
(C) Citrate and Oxaloacetate
(D) Fumarate and Carbon dioxide

2019

282. During gluconeogenesis in germinating seeds, which enzyme catalyzes the key committed step of converting oxaloacetate to phosphoenolpyruvate (PEP)?
(A) PEP carboxykinase (PEPCK)
(B) Pyruvate kinase
(C) Phosphofructokinase
(D) Rubisco

2010

283. Seed storage proteins are rapidly mobilized during germination. They are degraded into amino acids primarily within which subcellular compartment?
(A) Protein storage vacuoles
(B) Nucleus
(C) Lipid bodies
(D) Endoplasmic reticulum

2024

284. Phytic acid is a major storage form of which essential nutrient in seeds?
(A) Phosphorus
(B) Nitrogen
(C) Sulfur
(D) Potassium

2005

285. Which specific enzyme is synthesized during germination to hydrolyze phytic acid, releasing minerals for the growing seedling?
(A) Phytase
(B) Phosphatase
(C) Kinase
(D) ATP synthase

2025

286. What happens to the bulk of the amino acids generated by the hydrolysis of seed storage proteins?
(A) They are transported to the growing embryonic axis to synthesize new proteins.
(B) They are completely oxidized to CO_2 for energy.
(C) They are polymerized back into storage proteins in the cotyledons.
(D) They are secreted into the soil to attract symbiotic bacteria.

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2013

287. Which biochemical pathway is essential for converting the carbon skeletons of excess amino acids into sugars during early seedling growth?
(A) Gluconeogenesis
(B) Photorespiration
(C) The pentose phosphate pathway
(D) The Calvin cycle

2006

288. In the starchy endosperm of cereals, starch breakdown yields glucose and maltose. Which tissue primarily absorbs these simple sugars for transport to the growing embryo?
(A) The scutellum
(B) The root cap
(C) The coleorhiza
(D) The aleurone layer

2018

289. The induction and maintenance of primary seed dormancy during seed maturation on the mother plant is overwhelmingly controlled by which phytohormone?
(A) Abscisic acid (ABA)
(B) Auxin
(C) Gibberellic acid
(D) Ethylene

2006

290. The transition from a dormant seed to a germinating seed is fundamentally regulated by the dynamic antagonistic balance between ABA and which other hormone?

ensures that sulfate is only activated and reduced when the cellular pool of organic sulfur needs replenishment.

46. (B) Acting as a major cellular antioxidant and redox buffer
Glutathione is a sulfur-containing tripeptide that serves several critical physiological roles beyond protein structure. It acts as the primary cellular antioxidant and redox buffer, protecting cells from oxidative stress by scavenging reactive oxygen species. Additionally, glutathione is involved in the detoxification of xenobiotics and heavy metals, and it functions as a storage and transport form of reduced sulfur within plants.

47. (D) Glucosinolates
Glucosinolates are a group of sulfur-containing glucosides found primarily in the Brassicaceae family. These secondary metabolites act as a sophisticated chemical defense system against herbivores and pathogens. Upon tissue damage, they are hydrolyzed to release pungent and toxic compounds like isothiocyanates. The structural diversity of glucosinolates is derived from various amino acids, providing broad-spectrum protection for the entire plant.

48. (A) Glutathione and S-methylmethionine
While sulfate is the primary form of sulfur transported in the xylem, the phloem transport of sulfur from mature leaves to developing sinks involves organic molecules. Glutathione and S-methylmethionine are the predominant forms used for long-distance redistribution. These reduced sulfur compounds are highly mobile and serve as efficient donors for the synthesis of proteins and other sulfur-containing metabolites in sink tissues.

49. (B) Ammonification
Ammonification is a fundamental step in the global nitrogen cycle where organic nitrogenous compounds, such as proteins and nucleic acids from dead biomass, are decomposed by microorganisms. This process results in the release of nitrogen in the form of ammonia or ammonium ions. It converts complex organic nitrogen back into an inorganic form that can then be utilized by plants or nitrifiers.

50. (B) I, III, IV and V
Denitrification is a microbial process that significantly impacts soil nitrogen availability and the global atmosphere.
Characteristics of Denitrification:
1. It is an anaerobic process where bacteria use nitrate as a terminal electron acceptor instead of oxygen.
2. Genera like Pseudomonas and Bacillus are common denitrifiers.
3. It results in the conversion of nitrate to gaseous forms like nitrous oxide and dinitrogen.

51. (B) Nitrosomonas species
The first stage of nitrification, which involves the oxidation of ammonia to nitrite, is primarily carried out by a specific group of chemoautotrophic bacteria. Nitrosomonas species are the most well-known organisms responsible for this conversion in soil and aquatic environments. They derive energy from this oxidative process to fix carbon dioxide, playing a vital role in transforming ammonium into mobile nitrogen.

52. (D) Ammonia monooxygenase
The oxidation of ammonia in nitrifying bacteria like Nitrosomonas is initiated by the enzyme ammonia monooxygenase. This enzyme complex catalyzes the conversion of ammonia to hydroxylamine, requiring oxygen and reducing equivalents. It is a key rate-limiting step in the nitrification process and is highly sensitive to various environmental inhibitors, making it a critical control point for nitrogen transformations in soil.

53. (B) Hydroxylamine
During the microbial nitrification process, ammonia is not converted directly to nitrite in a single step. Hydroxylamine is the specific intermediate compound formed following the initial action of ammonia monooxygenase. Hydroxylamine is subsequently oxidized by hydroxylamine oxidoreductase to yield nitrite. This sequence of reactions allows the bacteria to extract energy from the chemical bonds of nitrogen compounds for their metabolic needs.

54. (D) Oxidation of nitrite to nitrate
Nitrite oxidoreductase is the enzyme responsible for the second stage of nitrification, occurring in bacteria such as Nitrobacter. Its specific function is to catalyze the oxidation of nitrite into nitrate.

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responsible for the actual fixation of carbon dioxide by incorporating it into ribulose-1,5-bisphosphate. The presence of RuBisCO allows the organism to build complex organic molecules from inorganic carbon, which is the defining characteristic of autotrophic metabolism.

127. (A) The energy yield from the oxidation of inorganic nitrogen compounds is very low.
Nitrifying bacteria are generally characterized by slow growth rates because the energy yield from the oxidation of inorganic nitrogen compounds is very low. Compared to the oxidation of organic sugars by heterotrophs, the conversion of ammonia to nitrite or nitrite to nitrate provides much less energy. Consequently, these bacteria must process large amounts of nitrogen to generate enough ATP.

128. (A) Oxygen (O_2)
Aerobic chemoautotrophic nitrifiers, such as Nitrosomonas and Nitrobacter, rely on aerobic respiration to generate energy. In their respiratory electron transport chain, molecular oxygen serves as the terminal electron acceptor. Electrons derived from the oxidation of ammonia or nitrite are passed through a series of membrane-bound carriers to oxygen, producing water and generating the proton motive force for ATP synthesis.

129. (A) Cytochrome c pool
In Nitrosomonas, the oxidation of hydroxylamine to nitrite is catalyzed by the enzyme hydroxylamine oxidoreductase. This reaction releases four electrons, which are immediately transferred to the cytochrome c pool in the periplasm. From there, the electrons can either flow downhill to oxygen to generate a proton gradient or uphill via reverse electron transport to reduce NAD^+ for biosynthetic purposes.

130. (A) I and II
Nitrobacter is a key organism in the second stage of nitrification and plays a vital role in soil nitrogen cycling.
It is a chemoautotroph that fixes carbon dioxide using the energy obtained from the chemical oxidation of nitrite to nitrate.
Unlike photosynthetic organisms, it does not utilize sunlight as an energy source, relying entirely on the energy harvested from its substrate.

131. (A) Ammonia oxidation yields more energy than nitrite oxidation.
Nitrosomonas generally has a higher cellular yield per mole of substrate than Nitrobacter because the oxidation of ammonia to nitrite yields more free energy than the oxidation of nitrite to nitrate. The redox potential of the ammonia/nitrite couple allows for more proton pumping compared to the nitrite/nitrate couple, resulting in more ATP and biomass per unit of nitrogen.

132. (A) As poly-beta-hydroxybutyrate (PHB) or glycogen-like polymers
Under favorable environmental conditions with an abundant supply of inorganic nitrogen and carbon dioxide, nitrifying bacteria store excess fixed carbon for later use. They typically accumulate these reserves in the form of poly-beta-hydroxybutyrate or glycogen-like polymers. These intracellular inclusions provide the energy and carbon skeletons needed for survival during periods of nutrient limitation or unfavorable conditions in the soil.

133. (A) S phase
The plant cell cycle is a highly regulated sequence of events leading to cell division. Chromosomal DNA replication occurs specifically during the S phase. During this period, the cell synthesizes a complete copy of its genetic material, ensuring that after division, each daughter cell receives a full set of chromosomes. This phase is preceded by G1 and followed by G2.

NODIA

134. (A) G1 phase
The G1 phase is typically the longest part of the cell cycle for most actively dividing plant cells. It represents the primary period of cellular growth and high metabolic activity. During this phase, the cell synthesizes proteins, increases its volume, and monitors environmental signals to decide whether to commit to another round of DNA replication and subsequent division.

135. (A) The preprophase band (PPB)
The preprophase band is a unique cortical ring of microtubules and actin filaments that forms in plant cells during the late G2 phase. It accurately predicts the future plane of cell division and the site where the cell plate will eventually fuse with the parental cell wall. The PPB disappears before mitosis begins, but it leaves behind a memory.

this reduction before the nitrite moves into the chloroplast.

64. (D) Rapid transport into the chloroplast for further reduction
Nitrite is highly reactive and potentially toxic to plant cells if allowed to accumulate. To ensure its rapid removal from the cytosol, the plant cell quickly transports the nitrite into the chloroplasts or proplastids. Once inside the plastid, nitrite is immediately reduced to ammonium by the enzyme nitrite reductase, which utilizes the abundant reducing power generated by the light reactions of photosynthesis.

65. (A) Siroheme and a [4Fe-4S] cluster
Nitrite reductase is the enzyme responsible for the six-electron reduction of nitrite to ammonium. Its catalytic mechanism involves two specific prosthetic groups that are essential for electron transfer: a [4Fe-4S] cluster and a specialized heme molecule called siroheme. These groups are tightly coupled, allowing for the direct and rapid transfer of electrons to the nitrite molecule bound at the active site.

66. (D) Reduced ferredoxin
In photosynthetic leaf tissues, the primary physiological electron donor for nitrite reductase is reduced ferredoxin. Ferredoxin is reduced by the photosynthetic electron transport chain in the thylakoid membranes during the light reactions. This high-energy electron carrier provides the six electrons necessary for the conversion of nitrite to ammonium, directly linking nitrogen assimilation to the light-dependent stage of photosynthesis in plants.

67. (A) Proplastids using ferredoxin reduced by the oxidative pentose phosphate pathway
In non-photosynthetic root tissues, nitrite reduction occurs within specialized plastids called proplastids. Since these tissues lack light-driven electron transport, the necessary reduced ferredoxin is generated through the oxidative pentose phosphate pathway. This pathway produces NADPH, which then reduces ferredoxin via ferredoxin-NADP+ reductase. This system ensures that nitrogen assimilation can proceed in underground organs using energy derived from stored carbohydrates.

68. (B) High levels of glutamine and other amino acids act as positive feed-forward activators of NR.
The regulation of nitrate assimilation is complex and sensitive to the plant's nitrogen status. While light and nitrate act as positive signals to stimulate nitrate reductase, high levels of downstream products like glutamine and other amino acids act as negative feedback regulators. The statement suggesting they act as positive activators is incorrect, as their accumulation signals that nitrogen demands are already met.

69. (A) Nitrate reductase
Molybdopterin is an essential organic cofactor that binds molybdenum at the active site of several plant enzymes. Nitrate reductase is strictly dependent on this cofactor for its catalytic function. Therefore, a genetic mutation or environmental condition that compromises the synthesis of molybdopterin will most immediately and severely impair the plant's ability to reduce nitrate, leading to nitrogen deficiency symptoms.

70. (C) P-IV, Q-II, R-I, S-III
Nitrate assimilation involves a coordinated series of proteins and enzymes to convert inorganic nitrogen into organic forms.
Functional Roles:
P. Nitrate reductase performs the first step by reducing nitrate to nitrite in the cytosol.
Q. Nitrite reductase catalyzes the subsequent reduction of nitrite to ammonium in the plastid.
R. 14-3-3 proteins act as inhibitors that bind and inactivate nitrate reductase.
S. Ferredoxin provides electrons for nitrite reduction.

NODIA

71. (D) Sudden transition to anaerobiosis or flooding
Nitrite accumulation in plant cells typically occurs when the rate of nitrate reduction exceeds the rate of nitrite reduction. This imbalance often happens during a sudden transition to anaerobic conditions, such as soil flooding. Under hypoxia, the availability of reducing power for nitrite reductase in the plastids is limited, while nitrate reductase in the cytosol may continue to function briefly.

72. (B) Nitrite
Nitrate reductase catalyzes the first committed step of nitrogen assimilation in plants. The enzyme facilitates the transfer of two electrons

It functions as an oxygen carrier that keeps the concentration of free oxygen low enough to protect nitrogenase while still delivering oxygen for bacteroid respiration.
The protein is a product of co-evolution, where the heme moiety is synthesized by the bacteria and the globin is plant-derived.

91. (A) Asparagine and Glutamine
Legumes are often classified by the chemical form in which they transport fixed nitrogen. Temperate legumes, such as joys and clover, are typically amide-transporters. In these plants, the ammonia produced in the nodules is assimilated into the amides asparagine and glutamine. These compounds are highly stable, have a high nitrogen-to-carbon ratio, and are efficiently transported through the xylem to sinks.

92. (D) Peroxisome
Tropical legumes like soybeans primarily export fixed nitrogen in the form of ureides, such as allantoin and allantoic acid. The synthesis of these compounds involves the catabolism of newly synthesized purines. The final steps of this pathway, specifically the conversion of uric acid into allantoin by the enzyme urate oxidase, occur within specialized peroxisomes located in the uninfected cells.

93. (A) Actinorhizal plants
Frankia is a genus of nitrogen-fixing actinomycetes that forms symbiotic root nodules in a diverse group of non-leguminous woody plants. These host plants, which include genera such as Alnus and Casuarina, are collectively referred to as actinorhizal plants. The symbiosis is functionally similar to the legume-rhizobium relationship, providing the host with fixed nitrogen and allowing colonization of nitrogen-poor soils.

94. (A) It facilitates the exchange of fixed nitrogen for plant dicarboxylic acids.
The symbiosome membrane is the physical interface between the host plant and the endosymbiotic bacteroid. Its primary role is to regulate the exchange of nutrients and signals. It facilitates the transport of fixed nitrogen from the bacteroid to the plant and the uptake of plant-derived carbon sources, mainly dicarboxylic acids like malate, which serve as the primary energy substrate.

95. (A) Flavonoid secretion and specific Nod factor recognition
The high degree of specificity in the legume-rhizobium symbiosis is determined during the very first stages of the interaction. It relies on the specific chemical structure of the flavonoids secreted by the plant and the corresponding recognition of these signals by the bacterial receptors. This ensures that only the correct rhizobial species produce the specific Nod factors required to trigger infection.

96. (B) Plant-derived nodule-specific cysteine-rich (NCR) peptides
In certain legumes, the transition of rhizobia from a free-living state to a fully differentiated bacteroid is driven by host-derived signals. Nodule-specific cysteine-rich peptides are secreted by the plant into the symbiosome. These peptides act as developmental regulators that direct the bacteria to undergo terminal differentiation, resulting in genome endoreduplication, loss of cell division capability, and induction of nitrogenase.

97. (A) Dinitrogenase (MoFe protein) and Dinitrogenase reductase (Fe protein)
The nitrogenase enzyme complex is the core catalyst of biological nitrogen fixation. it consists of two distinct protein components: Dinitrogenase reductase, also known as the Fe protein, and Dinitrogenase, or the MoFe protein. These two proteins must associate and dissociate repeatedly during the catalytic cycle to facilitate the transfer of electrons and the ultimate reduction of dinitrogen to ammonia.

98. (B) It hydrolyzes ATP to transfer electrons to the MoFe protein.
The Fe protein (dinitrogenase reductase) serves as the obligate electron donor to the MoFe protein. Its primary function is to bind ATP and undergo a conformational change upon ATP hydrolysis. This energy-driven change lowers the redox potential of its [4Fe-4S] cluster, allowing it to transfer a single electron to the MoFe protein. This process must be repeated multiple times.

99. (C) 16
Biological nitrogen fixation is an extremely energy-expensive process. The reduction of one mole of dinitrogen into two moles of ammonia requires the transfer of at least eight electrons. Since each electron transfer event from the Fe protein to the MoFe protein is coupled to the

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a carbon-rich environment in the rhizosphere. Tropical grasses typically exude organic acids, such as malate and succinate, through their roots. These C4-dicarboxylic acids are preferred carbon and energy sources for the bacteria, supporting their metabolic needs and the high ATP requirements of biological nitrogen fixation.

82. (B) Klebsiella pneumoniae
Klebsiella pneumoniae is a facultative anaerobic bacterium that can grow in both the presence and absence of oxygen. However, its ability to fix atmospheric nitrogen is strictly limited to anaerobic or microaerophilic conditions. This is because it lacks the robust oxygen-protection mechanisms found in obligate aerobes, making its nitrogenase enzyme highly vulnerable to oxygen-mediated inactivation in fully aerated environments.

83. (A) By strictly fixing nitrogen in the dark (temporal separation)
Trichodesmium is a non-heterocystous marine cyanobacterium that performs both photosynthesis and nitrogen fixation. To protect its nitrogenase from the oxygen produced during photosynthesis, it often employs temporal and physiological separation. In many environments, it restricts nitrogen fixation primarily to periods when photosynthetic activity is low or utilizes a specialized cell-colony structure that creates localized micro-zones with reduced oxygen.

84. (A) Molybdenum
Molybdenum is a critical microelement required in higher concentrations by diazotrophs because it is a fundamental component of the iron-molybdenum cofactor at the active site of the nitrogenase enzyme. This cofactor is where dinitrogen actually binds and is reduced to ammonia. Without sufficient molybdenum, free-living bacteria cannot assemble a functional nitrogenase complex, rendering them unable to fix atmospheric nitrogen.

85. (A) Inducing the expression of nodulation (nod) genes in rhizobia
The initiation of the legume-rhizobium symbiosis begins with a chemical dialogue. The plant root secretes specific flavonoid compounds into the rhizosphere. These molecules act as signals that are recognized by compatible rhizobia, where they bind to the NodD protein. This interaction triggers the expression of the bacterial nodulation genes, leading to the production of Nod factors that initiate infection.

86. (A) Lipo-chitooligosaccharides
Nod factors are the primary signaling molecules produced by rhizobia in response to plant flavonoids. Chemically, they are lipo-chitooligosaccharides. Their structure consists of a backbone of four or five N-acetylglucosamine residues, with a long-chain fatty acid attached to the non-reducing end. Specific chemical modifications on this backbone determine the host specificity, ensuring that only compatible rhizobia can infect a particular species.

87. (C) Root hair deformation and curling
Upon perceiving compatible Nod factors, the root hairs of the host plant undergo rapid and characteristic morphological changes. The earliest observable response is the deformation and curling of the root hair tip, often forming a shepherd's crook structure. This curling creates an enclosed pocket where the rhizobia can accumulate and initiate the formation of the infection thread to enter.

88. (A) Via a newly synthesized intracellular tubular structure called the infection thread
Rhizobia enter the plant root through an intracellular tubular structure known as the infection thread. This thread is synthesized by the plant cell in response to bacterial signals and is composed of cell wall material and plasma membrane. The bacteria multiply within this thread as it grows through the root tissue, eventually delivering the rhizobia into the target cells.

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89. (A) Bacteroids
Once the rhizobia are released from the infection thread into the cytoplasm of the host cortical cells, they are enclosed by a plant-derived peribacteroid membrane. Inside this symbiosome, the bacteria undergo significant physiological and morphological changes, differentiating into enlarged, non-dividing forms called bacteroids. These bacteroids are the active site of nitrogen fixation, expressing the nitrogenase enzyme to provide ammonia.

90. (A) I, II and IV
Leghaemoglobin is a specialized protein essential for maintaining the delicate oxygen balance within the nitrogen-fixing root nodule.

substrate reduction occurs, ensuring a steady flow of electrons during fixation.

109. (B) Oxidation of hydrogen gas to yield protons and electrons
Uptake hydrogenase is an enzyme found in many nitrogen-fixing bacteria that catalyzes the oxidation of hydrogen gas into protons and electrons. This enzyme is physiologically important because it recycles the hydrogen gas that is obligatorily produced as a byproduct of the nitrogenase reaction. By oxidizing this hydrogen, the bacterium can recover some of the energy that would otherwise be lost.

110. (A) Both A and R are true and R is the correct explanation of A.
The presence of an active uptake hydrogenase system significantly enhances the metabolic efficiency of biological nitrogen fixation.
Nitrogenase inevitably produces hydrogen gas, representing a loss of energy and electrons.
Hup^+ bacteria possess the enzyme required to recapture this hydrogen and oxidize it, thereby recovering reducing power and generating additional ATP through the respiratory chain in the bacteroid.

111. (A) Inner membrane facing the periplasmic space
In nitrogen-fixing bacteroids, the uptake hydrogenase is primarily localized on the inner cytoplasmic membrane, with its active site often facing the periplasmic space. This strategic positioning allows the enzyme to efficiently intercept the hydrogen gas produced by nitrogenase as it diffuses out of the cytoplasm. The electrons released from hydrogen oxidation are then funneled into the membrane-bound respiratory chain.

112. (C) Nickel and Iron
The uptake hydrogenases found in most rhizobia are metalloenzymes belonging to the NiFe-hydrogenase class. These enzymes require both nickel and iron at their active site to catalyze the reversible oxidation of hydrogen. The nickel and iron atoms are coordinated by cysteine residues and diatomic ligands, forming a unique catalytic center that is highly effective at breaking the strong bonds.

113. (D) It helps consume oxygen, aiding in the protection of nitrogenase.
Beyond energy recovery, the activity of uptake hydrogenase provides a secondary physiological benefit by helping to protect the oxygen-sensitive nitrogenase enzyme. The oxidation of hydrogen gas by the respiratory chain consumes oxygen as the terminal electron acceptor. This respiratory protection helps to maintain the extremely low internal oxygen concentrations required for nitrogenase to function, supplementing the role of leghaemoglobin.

114. (A) Cytochrome b or ubiquinone pool
When uptake hydrogenase oxidizes hydrogen gas within the bacteroid, the resulting electrons are transferred to the respiratory electron transport chain. In most diazotrophs, these electrons are typically donated to the quinone pool or specific b-type cytochromes. This allows the energy from hydrogen oxidation to be used to generate a proton motive force and subsequently synthesize ATP through oxidative phosphorylation.

115. (A) High availability of carbon and absence of hydrogen
The expression of the hydrogen uptake genes in rhizobia is a regulated process that responds to the physiological state of the cell. These genes are generally repressed under conditions where there is an abundant supply of carbon sources but an absence of hydrogen gas. This prevents the synthesis of the hydrogenase enzyme when its substrate is not available, conserving bacterial resources.

116. (D) They improve total dry matter yield by minimizing energy lost as evolved hydrogen gas.
Using Hup^+ strains of rhizobia for legume inoculation is considered an advantageous agricultural practice because it improves the overall productivity of the crop. By recycling the hydrogen gas produced during nitrogen fixation, these strains minimize the waste of metabolic energy and reducing power. This increased efficiency leads to higher rates of nitrogen fixation and improved total dry matter yield.

117. (A) Hydrogen gas evolves out of the nodule into the surrounding soil.
In bacteroids that are Hup-, the hydrogen gas produced as an obligatory byproduct of the nitrogenase reaction cannot be recycled. As a result, the hydrogen gas simply diffuses out

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hydrolysis of two molecules of ATP, a minimum of 16 moles are consumed.

100. (B) I, II, III and IV
The nitrogenase enzyme complex operates through a sophisticated biochemical mechanism with strict environmental requirements.
The reduction of dinitrogen is energy-intensive, requiring 16 ATP per N_2 molecule, and the enzyme is irreversibly inactivated by oxygen.
During its catalytic cycle, the enzyme inevitably produces hydrogen gas as a byproduct and is potently inhibited by carbon monoxide.

101. (A) The FeMo-cofactor (FeMoco)
The MoFe protein of the nitrogenase complex contains the actual site where atmospheric dinitrogen is bound and reduced. This active site is a complex metal cluster known as the FeMo-cofactor. It is composed of molybdenum, iron, and sulfur atoms arranged in a unique cage-like structure. The presence of molybdenum is essential for the stabilization of the intermediates formed during reduction.

102. (B) Nitrogenase strictly reduces only dinitrogen gas.
While nitrogenase is named for its ability to reduce dinitrogen, it is a relatively non-specific enzyme capable of reducing several small, triple-bonded molecules. The statement that it strictly reduces only dinitrogen gas is incorrect. It can also reduce substrates such as acetylene to ethylene, cyanide to methane, and azide to nitrogen, in addition to its obligatory reduction of protons.

103. (A) Ethylene, the product, is easily quantified by gas chromatography as a surrogate measure of nitrogenase activity.
The acetylene reduction assay is a standard technique used to quantify nitrogenase activity. Nitrogenase can reduce acetylene into ethylene. Ethylene is not naturally produced by the enzyme in significant amounts and can be easily and accurately measured using gas chromatography. This serves as an effective surrogate for measuring nitrogen fixation rates because the reduction is catalyzed by the same active site.

104. (A) Irreversible oxidation of the essential iron-sulfur clusters
The extreme oxygen sensitivity of nitrogenase is due to the nature of its essential metal clusters. Both the Fe protein and the MoFe protein contain iron-sulfur centers that are highly reactive. Exposure to oxygen leads to the rapid and irreversible oxidation of these clusters, which destroys the structural integrity and catalytic capacity of the enzyme, requiring anaerobic conditions for function.

105. (A) Vanadium- and Iron-only nitrogenases
In some diazotrophs, alternative nitrogenases are expressed when molybdenum availability is limiting in the environment. These enzymes are genetically distinct and utilize different metal cofactors at their active sites. The most common alternatives are vanadium-dependent nitrogenases and iron-only nitrogenases. Although they are less efficient than the molybdenum-dependent enzyme, they allow nitrogen fixation to continue under conditions of molybdenum deficiency.

106. (C) 8
The reduction of one mole of dinitrogen to two moles of ammonia requires six electrons. However, the nitrogenase reaction is obligatorily coupled with the reduction of two protons to produce one mole of hydrogen gas, which requires an additional two electrons. Therefore, a total of at least eight electrons must be transferred by the nitrogenase complex to complete the fixation process.

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107. (A) Binding and hydrolysis of ATP on the Fe protein
The transfer of electrons from the Fe protein to the MoFe protein is the central energy-transduction step in nitrogen fixation. This process is driven by the binding and subsequent hydrolysis of ATP on the Fe protein. The energy released from ATP hydrolysis induces a significant conformational change in the Fe protein, which physically pushes the electron into the MoFe protein during catalysis.

108. (A) It acts as an electron storage and transfer intermediate between the Fe protein and the FeMo-cofactor.
The P-cluster is a large iron-sulfur cluster located within the MoFe protein of nitrogenase. It serves as an essential intermediate in the electron transport chain of the enzyme. The P-cluster accepts electrons from the Fe protein and stores them temporarily before transferring them to the FeMo-cofactor, where the actual

This reaction completes the transformation of ammonium into nitrate, which is the most common form of nitrogen absorbed by higher plants, although the process also releases protons that acidify soil.

55. (B) Nitrous oxide (N_2O)
Denitrification is a multi-step reductive process that ideally converts nitrate all the way to dinitrogen gas. However, nitrous oxide is an obligate intermediate in this pathway. Incomplete denitrification, often caused by fluctuations in soil oxygen or pH, can lead to the significant escape of nitrous oxide into the atmosphere, where it acts as a potent greenhouse gas and ozone-depleting substance.

56. (B) Nitrification is an oxidative process, whereas denitrification is a reductive process.
Nitrification and denitrification are contrasting processes in the nitrogen cycle. Nitrification is an aerobic, oxidative process where ammonia is converted to nitrate by autotrophic bacteria. In contrast, denitrification is an anaerobic, reductive process where bacteria convert nitrate into gaseous nitrogen forms. While nitrification produces nitrate for plant use, denitrification leads to a net loss of available nitrogen from the soil ecosystem.

57. (A) Anaerobic oxidation of ammonium using nitrite to produce dinitrogen gas
The anammox process, or anaerobic ammonium oxidation, is a major component of the global nitrogen cycle, particularly in marine environments. It involves the biochemical reaction where ammonium is oxidized using nitrite as the electron acceptor under anaerobic conditions. This unique metabolism produces dinitrogen gas directly, bypassing traditional denitrification steps and providing an alternative pathway for returning fixed nitrogen to the atmosphere.

58. (D) Waterlogged, anaerobic soil conditions
Denitrification is most rapidly accelerated under waterlogged, anaerobic soil conditions. When soil pores are filled with water, oxygen diffusion is severely limited, forcing facultative anaerobic bacteria to use nitrate as an alternative terminal electron acceptor for respiration. This environment, combined with the presence of organic carbon as an energy source, leads to high rates of nitrogen loss as gaseous products.

59. (A) Proteases
Microorganisms initiate the process of ammonification by sealing extracellular enzymes to break down complex organic matter. Proteases are the primary enzymes responsible for degrading proteinaceous materials into smaller peptides and amino acids. These simpler nitrogen-containing compounds are then taken up by the microbes and deaminated internally, resulting in the release of ammonium ions into the surrounding soil environment for plants.

60. (A) Both A and R are true and R is the correct explanation of A.
The biological process of nitrification has a significant impact on soil chemistry, particularly its pH level. During the oxidation of ammonium ions to nitrate by nitrifying bacteria, the chemical reaction releases hydrogen protons as a byproduct. As these protons accumulate in the soil solution, they increase the acidity, leading to a measurable decrease in soil pH over time.

61. (A) FAD, Heme, and Molybdopterin
Nitrate reductase is a complex enzyme that facilitates the two-electron reduction of nitrate to nitrite. Each subunit of this homodimeric enzyme contains a short electron transport chain composed of three essential prosthetic groups: FAD, heme, and a molybdenum cofactor known as molybdopterin. These groups work sequentially to transfer electrons from NADH to the nitrate substrate at the active site.

62. (C) It is inactivated by phosphorylation and subsequent binding of 14-3-3 proteins.
In the dark, plant nitrate reductase activity is rapidly downregulated to prevent the accumulation of toxic nitrite. This inactivation involves a two-step post-translational mechanism: first, the enzyme is phosphorylated at a specific serine residue by an NR-kinase; second, the phosphorylated enzyme binds to 14-3-3 inhibitor proteins, which physically blocks the catalytic activity of the enzyme until light returns.

63. (A) Cytosol
In a typical leaf mesophyll cell, nitrate reductase is primarily localized in the cytosol. This is where the initial step of nitrate assimilation occurs, converting nitrate absorbed from the soil or transported through the xylem into nitrite. The enzyme utilizes NADH, which is readily available in the cytosolic compartment, to drive

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of the bacteroids and the root nodule into the surrounding soil. This represents a significant loss of energy, as approximately 25% of the electrons used by nitrogenase are diverted to hydrogen.

118. (A) It consists of a large subunit containing the NiFe active site and a small subunit with Fe-S clusters.
A typical NiFe-uptake hydrogenase is a heterodimeric protein consisting of two distinct subunits. The large subunit contains the NiFe active site where the chemical reaction of hydrogen oxidation occurs. The small subunit contains multiple iron-sulfur clusters that serve as an internal electron transport chain, carrying the electrons from the active site to the membrane-bound electron acceptors of the chain.

119. (B) It can stimulate the growth of distinct hydrogen-oxidizing soil bacteria.
The evolution of hydrogen gas from Hup- root nodules into the surrounding soil can have significant ecological effects on the rhizosphere. This hydrogen serves as a rich energy source that stimulates the growth of specialized hydrogen-oxidizing bacteria. These microbes can increase in density around the roots, potentially influencing the soil microbial community structure and contributing to overall carbon cycling.

120. (A) P-II, Q-I, R-IV, S-III
Various enzymes and proteins work in concert to manage the complex biochemistry of nitrogen fixation and ammonia assimilation in root nodules.
Protein Functions:
P. Nitrogenase produces obligatory hydrogen gas during dinitrogen reduction.
Q. Uptake hydrogenase functions to consume and recycle this hydrogen gas.
R. Leghaemoglobin buffers oxygen levels.
S. Glutamine synthetase incorporates fixed ammonia.

121. (A) Atmospheric carbon dioxide (CO_2)
Chemoautotrophic nitrifying bacteria, such as Nitrosomonas and Nitrobacter, are unique because they do not require organic matter for their growth. Instead, they derive all their cellular carbon from atmospheric carbon dioxide. They use the energy obtained from the oxidation of inorganic nitrogen compounds to drive the fixation of CO_2 into organic molecules, playing a fundamental role in ecosystems.

122. (A) Calvin cycle
Nitrosomonas and Nitrobacter primarily employ the Calvin-Benson cycle to fix carbon dioxide. This is the same fundamental biochemical pathway used by photosynthetic plants and cyanobacteria. By using this cycle, these nitrifying bacteria can synthesize the organic building blocks required for cellular structure and metabolism using the energy harvested from the oxidation of ammonia or nitrite in the soil.

123. (A) Oxidation of ammonia to nitrite
Nitrosomonas is a chemoautotrophic bacterium that derives the energy necessary for its growth and carbon fixation from a specific inorganic reaction. It oxidizes ammonia into nitrite. This oxidative process releases energy and electrons, which are then used by the bacterium to generate ATP and reducing power required for the fixation of carbon dioxide and other essential biosynthetic activities.

124. (D) By utilizing reverse electron transport driven by the proton motive force
Many chemoautotrophs face a thermodynamic problem because their inorganic electron donors have a higher redox potential than the NAD^+/NADH couple. To generate the NADH needed for carbon fixation, these bacteria utilize reverse electron transport. This process uses energy from the proton motive force to push electrons against their natural thermodynamic gradient, allowing the reduction of NAD+ to NADH.

125. (A) Chemoautotrophy is the primary energy mode for rhizobia inside the root nodule.
While some rhizobia have the genetic capacity to act as chemoautotrophs under specific free-living conditions by oxidizing hydrogen, this is not their primary mode of energy generation. Inside the root nodule, bacteroids rely strictly on the supply of organic acids provided by the host plant. The statement that chemoautotrophy is the primary energy mode inside the nodule is incorrect.

126. (B) Ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO)
For a bacterium to be classified as a true chemoautotroph using the Calvin cycle, it must possess the enzyme RuBisCO. This enzyme is

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to the nitrate molecule. This specific biochemical reaction results in the immediate production of nitrite. Following this step, the nitrite must be further reduced to ammonium by other enzymes before it can be incorporated into various amino acids and organic compounds.

73. (A) Azotobacter chroococcum
Azotobacter chroococcum is a classic example of a free-living, aerobic bacterium capable of biological nitrogen fixation. Unlike symbiotic bacteria that require a host plant, Azotobacter survives and fixes atmospheric nitrogen independently in the soil. It has evolved specialized mechanisms, such as high respiratory rates, to protect its oxygen-sensitive nitrogenase enzyme while thriving in well-oxygenated environments suitable for its growth.

74. (D) Azospirillum brasilense
Associative nitrogen fixation involves bacteria that live in close proximity to plant roots without forming specialized structures. Azospirillum brasilense is a prominent diazotroph known for establishing such relationships with the roots of important tropical grasses, including sugarcane and maize. These bacteria colonize the root surface and intercellular spaces, providing fixed nitrogen in exchange for carbon-rich exudates from the host plant.

75. (B) By maintaining an exceptionally high rate of respiration
Azotobacter species thrive in aerobic environments but must protect their nitrogenase enzyme, which is irreversibly inactivated by oxygen. They achieve this primarily through respiratory protection, maintaining an exceptionally high rate of oxygen consumption at the cell membrane. This rapid respiration ensures that the internal concentration of free oxygen remains extremely low, allowing nitrogen fixation to proceed even in aerated soils.

76. (C) Anabaena
Anabaena is a genus of filamentous cyanobacteria that resolves the conflict between oxygenic photosynthesis and oxygen-sensitive nitrogen fixation through spatial separation. They develop specialized, thick-walled cells called heterocysts. These cells lack Photosystem II and possess a specialized envelope that limits oxygen diffusion, providing an anaerobic internal environment where the nitrogenase enzyme can function efficiently to fix atmospheric nitrogen for the colony.

77. (A) Fermentation
Clostridium pasteurianum is an obligate anaerobic bacterium that fixes nitrogen in environments completely devoid of oxygen. Because it lacks an electron transport chain for oxidative phosphorylation, it relies primarily on fermentation to generate the ATP and reducing power required for the nitrogenase reaction. This metabolic mode allows it to inhabit deep soil layers and sediments where organic matter is readily fermented.

78. (A) Nitrogenase expression is upregulated in the presence of high external ammonium.
Nitrogen fixation is a highly regulated process because of its extreme energy cost. In free-living diazotrophs, the expression of the nitrogenase enzyme is strictly downregulated or repressed in the presence of high concentrations of external ammonium. The statement that nitrogenase is upregulated by ammonium is incorrect, as the bacterium will preferentially use available fixed nitrogen rather than expend energy.

79. (A) Repression by the NifL-NifA two-component regulatory system
In free-living diazotrophs like Klebsiella, the expression of nitrogen fixation genes is controlled by a sophisticated regulatory system. The NifL-NifA two-component system acts as the primary sensor. NifA is a transcriptional activator, while NifL is a sensor protein that inhibits NifA in the presence of high oxygen or fixed nitrogen. This mechanism ensures that nitrogenase is only synthesized under appropriate conditions.

80. (A) I and II
Diazotrophs are categorized based on their lifestyle and relationship with host plants for nitrogen fixation. Azotobacter and Beijerinckia are strictly free-living bacteria that fix atmospheric nitrogen independently in the soil without forming symbiotic associations. In contrast, Frankia is a symbiotic actinomycete that forms specialized root nodules in actinorhizal plants, representing a distinct ecological group compared to free-living genera.

81. (A) Organic acids like malate and succinate
In associative symbioses between tropical grasses and bacteria like Azospirillum, the plant provides

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136. (D) Separation of sister chromatids
The transition from metaphase to anaphase is a critical step in mitosis that ensures equal distribution of genetic material. This event is distinctly marked by the simultaneous separation of sister chromatids at their centromeres. Once separated, the chromatids are referred to as daughter chromosomes and are pulled toward opposite poles of the cell by the shortening of spindle microtubules.

137. (A) Golgi apparatus
Unlike animal cells that divide by furrowing, plant cells undergo cytokinesis through the formation of a cell plate. The Golgi apparatus is the organelle primarily responsible for this process. It packages cell wall components and membrane materials into secretory vesicles, which are then transported along microtubules to the center of the dividing cell where they fuse to form the wall.

138. (A) Phragmoplast
The phragmoplast is a specialized structure composed of microtubules, actin filaments, and endoplasmic reticulum that forms between the two daughter nuclei during late anaphase and telophase. Its primary function is to guide the delivery and fusion of Golgi-derived vesicles to form the cell plate. The phragmoplast expands outward until the growing cell plate fuses with the mother cell wall.

139. (A) Endoreduplication
Endoreduplication is a specialized variant of the cell cycle where a plant cell undergoes multiple rounds of DNA replication without entering mitosis or cytokinesis. This process leads to the formation of polyploid cells with significantly increased nuclear DNA content. It is common in tissues with high metabolic activity or large cell sizes, such as the endosperm and certain root cells.

140. (B) I and II
The progression of the plant cell cycle is governed by critical checkpoints that ensure the correct timing and fidelity of division.
The G1/S transition acts as the primary control point for entering DNA synthesis, while the G2/M transition regulates the initiation of mitosis.
These checkpoints are highly sensitive to internal signals and environmental factors like nutrient availability and hormones.

141. (A) G0 phase
Cells that exit the active cell cycle and stop dividing are said to enter the G0 phase. In this state, cells are metabolically active and can undergo specialized differentiation to perform specific physiological functions. Some cells remain in G0 permanently, while others can be stimulated by hormones or wounding to re-enter the active cell cycle and resume division as needed.

142. (A) It is a gap phase between DNA replication and mitosis used for checking DNA integrity.
The G2 phase is the interval between the completion of DNA replication in S phase and the beginning of mitosis. It serves as a critical period for the cell to monitor its genome for any errors or damage that may have occurred during replication. During G2, the cell also synthesizes proteins necessary for spindle formation and prepares for mitosis.

143. (A) Centrioles / Centrosomes
Higher plant cells are distinguished from animal cells by the absence of centrioles and centrosomes during spindle formation. Despite lacking these traditional microtubule-organizing centers, plant cells effectively form a functional mitotic spindle. They utilize a diffuse system of microtubule nucleation that occurs across the nuclear envelope and within the cytoplasm, allowing for accurate chromosome segregation during division in mitosis.

144. (A) Telophase
Telophase is the final stage of mitosis where the nuclear envelope fully reforms around each of the two sets of daughter chromosomes at opposite poles. During this phase, the condensed chromosomes begin to de-condense back into chromatin, the nucleoli reappear, and the mitotic spindle breaks down. This stage sets the scene for the final separation of cells.

145. (A) Cyclin-dependent kinases (CDKs)
The molecular engine that drives the progression of the plant cell cycle is a family of enzymes known as cyclin-dependent kinases. These kinases are characterized by their requirement for a regulatory cyclin subunit to become

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Phosphatases type 2C act as negative regulators by binding to and inhibiting SnRK2 signaling kinases. When ABA binds to its receptors, the receptor-hormone complex inhibits the PP2Cs. This inhibition releases the SnRK2 kinases, allowing them to initiate the response.

203. (A) SnRK2 kinases
Upon the inhibition of PP2C phosphatases by the ABA-receptor complex, the SnRK2 family of kinases becomes active through autophosphorylation. These kinases then phosphorylate several downstream targets, including ABF transcription factors that regulate gene expression and various ion channels in guard cells. This phosphorylation cascade is the primary mechanism by which ABA triggers physiological responses like stomatal closure.

204. (A) Dephosphorylation and nuclear accumulation of the transcription factors BES1 and BZR1
Brassinosteroid signaling is initiated by the binding of the hormone to the extracellular domain of the BRI1 receptor kinase. This triggers a phosphorylation cascade that ultimately inhibits a negative regulator kinase called BIN2. In the absence of BIN2 activity, the transcription factors BES1 and BZR1 become dephosphorylated. These dephosphorylated factors then accumulate in the nucleus to promote growth.

205. (A) Osmoprotectants (Compatible solutes)
In response to osmotic stresses such as drought or high salinity, plants accumulate specific low-molecular-weight organic compounds known as osmoprotectants. These molecules are highly soluble and do not interfere with normal cellular metabolism at high concentrations. By accumulating these solutes, plants can lower internal water potential, which helps maintain turgor pressure and protects cellular structures from damage.

206. (A) Glycine betaine
Glycine betaine is a quintessential compatible solute that is widely synthesized by many crop plants during abiotic stress. It is a quaternary ammonium compound that accumulates in the cytosol and organelles to stabilize proteins and membranes against the destabilizing effects of high salinity and water deficit. Its accumulation is a key trait associated with increased stress tolerance in crops.

207. (A) Superoxide anion ($O_2^{\cdot -}$)
Abiotic stresses often lead to the overproduction of Reactive Oxygen Species. The superoxide anion is one of the primary radicals generated in the chloroplasts and mitochondria under stress. The enzyme Superoxide Dismutase provides the first line of defense by catalyzing the disproportionation of this radical into oxygen and hydrogen peroxide, which is then further detoxified by other antioxidants.

208. (A) Scavenging hydrogen peroxide to prevent oxidative damage
The ascorbate-glutathione cycle is a critical antioxidant system found in several cellular compartments, including chloroplasts. Its primary function is the efficient scavenging of hydrogen peroxide to prevent oxidative damage. The cycle uses ascorbate and glutathione as electron donors, and the reducing power is supplied by NADPH. This system is vital for maintaining the redox balance of the plant.

209. (A) COR (Cold-Regulated) genes via CBF/DREB transcription factors
Cold acclimation is the process where plants improve freezing tolerance following exposure to low, non-freezing temperatures. This response is centrally mediated by the CBF/DREB family of transcription factors. These factors bind to the promoters of Cold-Regulated genes, triggering their expression. The products of COR genes include cryoprotective proteins and enzymes for compatible solute synthesis, which stabilize cell components.

210. (C) A is true but R is false.
Proline accumulation is one of the most widely recognized biochemical responses to water deficit and salinity stress in various plant species. While its presence is a reliable marker of stress, the reason provided is incorrect because proline does not primarily function as a structural component. Instead, it acts as a compatible solute that provides osmotic adjustment and membrane stabilization.

211. (A) Chloroplast
The chloroplast is considered the major site of Reactive Oxygen Species generation in plant cells, particularly under conditions of light-induced abiotic stress. During intense light or when CO2 assimilation is restricted, the photosynthetic electron transport chain becomes over-reduced.

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and the assembly of the mitotic spindle, thereby initiating the physical process of division.

155. (A) CDKB
The CDKB class is a plant-specific group of cyclin-dependent kinases that are distinguished by their unique expression pattern. Unlike the constitutive CDKA, CDKB protein and mRNA levels accumulate strictly during the G2 and M phases of the cell cycle. This tight regulation makes CDKB a primary controller of the entry into mitosis, ensuring these events only occur correctly.

156. (A) Ubiquitin
In plants, the targeted degradation of key cell cycle regulators, such as cyclins and inhibitory proteins, is achieved via the ubiquitin-proteasome pathway. Proteins destined for destruction are covalently tagged with a small protein called ubiquitin. This polyubiquitin chain is recognized by the 26S proteasome, which unfolds and degrades the tagged protein, ensuring rapid and irreversible changes in status.

157. (A) By activating H+-ATPases to lower apoplastic pH.
The acid growth hypothesis explains how auxins induce rapid cell elongation. Auxins stimulate the activity of plasma membrane H+-ATPases, which pump protons out of the cell into the cell wall. This lowering of the apoplastic pH activates specific proteins, such as expansins, that loosen the cell wall structure. This loosening allows the cell to expand under turgor pressure.

158. (A) They are non-enzymatic proteins that disrupt hydrogen bonds between cellulose and hemicellulose in a pH-dependent manner.
Expansins are unique, non-enzymatic proteins located in the plant cell wall. Their primary function is to facilitate cell wall loosening during growth. They work by disrupting the hydrogen bonds between cellulose microfibrils and the cross-linking hemicellulose polymers. This action is pH-dependent and allows the polymers to slide past one another, enabling the cell wall to expand under turgor pressure.

159. (A) Turgor pressure
Cellular expansion in plants is a physical process that requires a driving force to overcome the mechanical resistance of the cell wall. Turgor pressure provides this required force. It is the internal hydrostatic pressure exerted by the cell's contents against the plasma membrane and cell wall. When the cell wall is loosened, turgor pressure causes the wall to yield.

160. (A) Both A and R are true and R is the correct explanation of A.
The directional growth of plant organs in response to light and gravity is regulated by the differential distribution of auxin. In shoots, high auxin concentrations stimulate cell elongation, leading to bending. However, roots are much more sensitive, and the same high auxin concentrations actually inhibit elongation on the lower side, leading to downward bending, explaining the opposite tissue responses.

161. (A) Auxin
Standard theories of plant tropisms propose that directional growth responses are mediated by the lateral redistribution of auxin. In response to stimuli like light or gravity, auxin is transported asymmetrically across the organ. This creates a concentration gradient that induces differential rates of cell elongation on opposite sides, ultimately causing the plant to bend toward or away from the stimulus.

162. (A) Statoliths
In plant roots, the perception of gravity occurs primarily within specialized cells called statocytes located in the root cap. These cells contain heavy, starch-filled amyloplasts known as statoliths. Due to their density, statoliths sediment to the lowest part of the cell in response to gravity. This physical settling acts as the primary sensor that triggers the biochemical signaling for gravitropic bending.

163. (A) High auxin on the lower side inhibits cell elongation, while the upper side elongates.
When a root is placed horizontally, statoliths sediment on the lower side of the statocytes, leading to the accumulation of auxin on the lower side of the root tip. Because root tissues are highly sensitive to auxin, these elevated concentrations inhibit cell elongation. Meanwhile, cells on the upper side continue to elongate normally, which results in the root bending downward.

164. (A) Phototropins
Phototropism is the growth of a plant organ toward or away from unidirectional light. This response is primarily initiated by the perception

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catalytically active. By phosphorylating specific target proteins at precise times, CDKs trigger the essential biochemical and structural changes required for DNA replication and mitosis.

146. (A) By acting as the regulatory subunit that must bind to CDK for its catalytic activity
Cyclins are the primary regulatory subunits of CDKs. For a CDK to become active and phosphorylate its substrates, it must first bind with a specific cyclin protein. The levels of different cyclins fluctuate throughout the cell cycle, ensuring that CDKs are only active during appropriate phases. This binding induces a conformational change allowing the CDK to recognize its targets.

147. (A) D-type cyclins
In higher plants, the transition from the G1 phase to the S phase is specifically controlled by the activity of the CDKA complexed with D-type cyclins. The expression of D-type cyclins is highly sensitive to external signals such as nutrient availability and plant hormones. This allows the plant to integrate environmental information and decide whether to initiate DNA synthesis.

148. (A) The Anaphase-Promoting Complex/ Cyclosome (APC/C)
The Anaphase-Promoting Complex/Cyclosome is a large E3 ubiquitin ligase that plays a crucial role in regulating the exit from mitosis. It targets specific proteins, including mitotic cyclins, for degradation by the 26S proteasome. By destroying these cyclins, the APC/C allows the cell to complete mitosis and move into the next G1 phase, ensuring the cycle proceeds correctly.

149. (A) It phosphorylates RBR, releasing E2F transcription factors to promote S phase genes.
The retinoblastoma-related protein is a key negative regulator of the G1/S transition in plants. It acts by binding to and inhibiting E2F transcription factors required for S-phase genes. When CDK-cyclin complexes become active during G1, they phosphorylate RBR. This phosphorylation causes RBR to release the E2F factors, thereby promoting the initiation of DNA replication and cycle progression.

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150. (A) II, III and IV
The activity of cyclin-dependent kinases is tightly controlled by multiple inhibitory mechanisms to prevent premature or incorrect cell division.
Inhibitory Factors:
P. Kip-related proteins act as direct inhibitors that bind and block CDK-cyclin complexes.
Q. WEE1 kinase performs inhibitory phosphorylation on the CDK catalytic subunit.
R. The APC/C complex mediates the proteolysis of cyclins.

151. (A) Cytokinin
Cytokinins are plant hormones that play a fundamental role in promoting cell division. They exert this effect primarily by inducing the expression of D-type cyclins. By increasing the levels of these cyclins, cytokinins stimulate the activation of CDK complexes that drive the cell through the G1/S checkpoint. This links the hormonal control of development directly to the cell cycle machinery.

152. (A) Mitotic CDK-Cyclin B complex
Endoreduplication is a process where cells replicate their DNA but skip mitosis, resulting in polyploidy. Molecularly, this transition is often triggered by the downregulation of the mitotic CDK-Cyclin B complex. When the activity of this specific complex is inhibited or its cyclins are degraded prematurely, the cell cannot enter mitosis and instead undergoes another round of DNA synthesis.

153. (A) It phosphorylates and inhibits CDK to arrest the cell cycle in response to DNA damage.
WEE1 kinase is a critical regulator of the plant cell cycle that acts as a safety brake. It specifically phosphorylates the CDK protein on a conserved tyrosine residue, which inhibits its catalytic activity. This phosphorylation serves to arrest the cell cycle, particularly at the G2/M transition, in response to DNA damage, allowing the cell time to repair its genome.

154. (A) A-type and B-type cyclins
The transition from the G2 phase into mitosis is primarily regulated by the activation of complexes consisting of CDKA or the plant-specific CDKB combined with A-type and B-type cyclins. These complexes phosphorylate a wide array of proteins required for nuclear envelope breakdown, chromosome condensation,

to decreased internode elongation and more compact growth.

174. (A) Alpha-amylase
During the germination of cereal grains, gibberellins produced by the embryo act as a signal to the aleurone layer. In response to GA, the aleurone cells synthesize and secrete hydrolytic enzymes, most notably alpha-amylase. This enzyme is essential for the mobilization of energy reserves as it breaks down the starchy endosperm into simple sugars used by the growing embryo.

175. (A) ATP or ADP and dimethylallyl diphosphate (DMAPP)
The biosynthesis of cytokinins involves the transfer of an isopentenyl group to an adenine molecule. This reaction is catalyzed by the enzyme isopentenyl transferase. The most common precursor molecule utilized by IPT is either ATP or ADP, which receives the five-carbon side chain from dimethylallyl diphosphate. This produces the active cytokinin backbone, which is further modified into natural zeatin.

176. (A) Zeatin
Zeatin is the most abundant and universally distributed natural cytokinin found in higher plants. It was originally discovered in immature maize kernels and exists in both cis- and trans-isomers, with the trans-isomer being the most biologically active form. Zeatin plays a central role in promoting cell division, delaying leaf senescence, and regulating various aspects of development and environmental responses.

177. (A) Auxin and Cytokinin
In plant tissue culture, the relative concentrations of auxin and cytokinin are critical for controlling organogenesis. A high ratio of auxin to cytokinin typically promotes the formation of roots from callus tissue. Conversely, a low ratio of auxin to cytokinin stimulates the differentiation and growth of shoots. An intermediate balance of both hormones generally results in the proliferation of undifferentiated callus.

178. (A) Root apical meristem
While cytokinins are produced in various parts of the plant, the root apical meristem is recognized as the predominant site of synthesis. From the roots, cytokinins are transported upward to the shoot system via the xylem transpiration stream. This movement allows the roots to communicate their status to the rest of the plant, influencing shoot growth and leaf longevity.

179. (A) Xylem
Auxin is a fundamental regulator of vascular tissue differentiation in plants. High concentrations of auxin, such as those found during leaf development or wounding responses, primarily induce the differentiation of procambial cells into xylem elements. This relationship ensures that the plant develops a functional transport system that is properly aligned with the sites of hormone production and mechanical needs.

180. (A) Tryptophan → Indole-3-pyruvate (IPyA) → Indole-3-acetic acid (IAA)
The primary tryptophan-dependent pathway for the biosynthesis of indole-3-acetic acid in most plants involves the indole-3-pyruvic acid intermediate. In this pathway, tryptophan is first converted into IPyA by a transaminase enzyme. Subsequently, the IPyA is decarboxylated and oxidized to form IAA by the YUCCA family of flavin-containing monooxygenases. This two-step sequence is a major route for auxin.

181. (A) Xanthoxin
The biosynthesis of abscisic acid in higher plants is part of the carotenoid pathway. The process begins with the cleavage of a 40-carbon xanthophyll by the enzyme NCED. This reaction produces a 15-carbon intermediate called xanthoxin. Xanthoxin then moves from the plastid to the cytosol, where it is further oxidized and converted into the active ABA molecule during stress.

182. (A) Methionine
Ethylene is a simple gaseous hormone that is unique among plant regulators. In higher plants, it is synthesized from the essential amino acid methionine. Methionine is first converted to S-adenosylmethionine, which then serves as the substrate for the subsequent steps of the pathway that ultimately release ethylene to regulate ripening, senescence, and responses to environmental stress factors.

183. (A) ACC synthase
The biosynthesis of ethylene is highly regulated, and the rate-limiting step is the conversion of S-adenosylmethionine into 1-aminocyclopropane-1-carboxylic acid. This reaction is catalyzed by

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of blue light by a family of photoreceptors called phototropins. Upon activation, these receptors trigger the lateral transport of auxin across the shoot, which leads to greater elongation on the shaded side and causes bending toward the light.

165. (A) Exocytosis of secretory vesicles from the Golgi network
During the process of cell wall expansion, the plant must continuously incorporate new material to maintain wall thickness and strength. Newly synthesized matrix polysaccharides are produced in the Golgi apparatus. These components are then packaged into secretory vesicles and delivered to the plasma membrane via exocytosis, where they are released and integrated into the existing wall structure for growth.

166. (A) Expansion can proceed indefinitely without the uptake of water.
Plant cell expansion is a complex process that integrates water uptake, turgor pressure, and wall mechanics. The statement that expansion can proceed indefinitely without water uptake is incorrect. Water uptake is essential to maintain the turgor pressure that provides the physical force for growth. Without a continuous supply of water to the expanding cell, turgor would drop rapidly.

167. (A) Apical dominance
Apical dominance is a developmental phenomenon where the main central stem of a plant grows more vigorously and suppresses the growth of lateral buds. This process is primarily controlled by the production of auxin in the shoot apical meristem. The downward flow of auxin inhibits the development of side branches, ensuring that resources are allocated toward vertical growth for light.

168. (A) Auxin and Ethylene
Thigmotropism is the directional growth of a plant organ in response to physical contact, such as the coiling of tendrils. This rapid response is regulated by the cooperative action of two plant hormones, auxin and ethylene. Physical touch triggers a redistribution of these hormones, which leads to differential growth rates on the two sides of the tendril, causing it to coil.

169. (A) Tryptophan
Indole-3-acetic acid is the most abundant and important natural auxin found in plants. Its primary biosynthetic precursor is the essential amino acid tryptophan. Plants possess several metabolic pathways to synthesize IAA from tryptophan. These routes involve various intermediates such as indole-3-pyruvic acid or tryptamine, which are then converted into the active hormone to regulate various aspects of plant growth.

170. (B) P-II, Q-IV, R-I, S-III
Phytohormones are chemical messengers that regulate virtually every aspect of a plant's life cycle through their diverse physiological effects.
Hormonal Functions:
P. Auxin is characterized by its roles in apical dominance and adventitious root initiation.
Q. Gibberellin stimulates bolting and internode elongation.
R. Cytokinin delays leaf senescence.
S. Abscisic acid signals stomatal closure.

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171. (A) PIN proteins
The polar transport of auxin is a unique feature of plant development, characterized by its unidirectional movement from the shoot tip to the root. this process is strictly mediated by the asymmetric cellular localization of PIN proteins. These are specialized efflux carrier proteins located on the plasma membrane. By being positioned at the base of cells, PIN proteins ensure directional flow.

172. (A) Plastid, Endoplasmic Reticulum, and Cytosol
The biosynthesis of gibberellins is a complex multi-step process that is spatially organized within the plant cell. Early stages, involving the formation of ent-kaurene, occur in the plastids. Subsequent oxidative steps to form GA12 occur in the endoplasmic reticulum. Finally, the conversion of GA12 into various active gibberellins takes place within the cytosol, integrating several organelles into production.

173. (A) Ent-kaurene oxidase
Many commercial growth retardants used in agriculture function by inhibiting gibberellin biosynthesis to produce shorter plants. A major target for these chemicals is the early part of the pathway, specifically the enzymes ent-copalyl diphosphate synthase and ent-kaurene oxidase. By blocking these enzymes, the plant's production of active GAs is reduced, leading

defects in the jasmonate signaling pathway, as seedlings show reduced root growth.

193. (A) Aux/IAA proteins
The signal transduction pathway for auxin is characterized by the rapid regulation of gene expression through protein degradation. At low auxin levels, a family of repressor proteins known as Aux/IAA proteins bind to and inhibit Auxin Response Factors. When auxin levels rise, it facilitates the interaction between Aux/IAA proteins and an E3 ubiquitin ligase, leading to the rapid degradation.

194. (A) Receptor and F-box component of the SCF complex.
The TIR1 protein is the core receptor for auxin in plants. It functions as an F-box protein that is part of the SCF E3 ubiquitin ligase complex. TIR1 possesses a binding pocket that directly accepts an auxin molecule. Once auxin is bound, it acts as a molecular glue, enhancing the affinity of TIR1 for the Aux/IAA repressor proteins.

195. (A) DELLA proteins
In the gibberellin signaling pathway, growth is restricted by a family of repressor proteins called DELLA proteins. These proteins are located in the nucleus and act to inhibit the expression of GA-responsive genes. Upon perception of gibberellin, the DELLA proteins are targeted for ubiquitination and subsequent degradation by the 26S proteasome, which releases the inhibition and allows elongation.

196. (A) GID1
The GID1 protein is the primary soluble receptor for gibberellins in plants. When GID1 binds to a bioactive GA molecule, it undergoes a conformational change that allows it to interact with the DELLA repressor proteins. This GID1-GA-DELLA complex is then recognized by a specific E3 ubiquitin ligase, which leads to the degradation of the DELLA protein and triggers response.

197. (A) Histidine kinases (e.g., AHKs)
Cytokinin signaling is based on a modified two-component system. The primary receptors for cytokinins are histidine kinases. These receptors are typically located in the endoplasmic reticulum or plasma membrane. Upon binding cytokinin, the receptor undergoes autophosphorylation and initiates a phosphorelay cascade that eventually leads to the regulation of gene expression in the nucleus through the activation of response regulators.

198. (A) Type-B ARRs (Arabidopsis Response Regulators)
The cytokinin signaling cascade involves the transfer of a phosphoryl group from receptors to histidine phosphotransfer proteins, which then move into the nucleus. In the nucleus, the phosphotransfer proteins transfer the phosphate to Type-B ARRs. These Type-B ARRs are transcription factors that, when phosphorylated, become active and bind to the promoters of cytokinin-responsive genes to initiate the response.

199. (A) COI1-JAZ
The perception of jasmonic acid-isoleucine, the bioactive form of the hormone, requires the COI1 protein. COI1 is an F-box protein that serves as the receptor within an SCF E3 ubiquitin ligase complex. When JA-Ile is present, it promotes the binding of COI1 to JAZ repressor proteins. This results in the degradation of the JAZ proteins, thereby releasing transcription factors.

200. (A) Receptors activate CTR1 to suppress the response.
Ethylene receptors function as negative regulators of the signaling pathway. In the absence of ethylene, the receptors are active and stimulate a protein kinase called CTR1. CTR1 then acts to suppress the downstream ethylene response. When ethylene binds to the receptors, they are inactivated, which turns off CTR1 and allows the signaling pathway to proceed toward gene activation.

201. (A) EIN3 and EIL1 transcription factors
Downstream signaling of ethylene culminates in the activation of the EIN3 and EIL1 transcription factors. These are the master regulators of the ethylene response in the nucleus. They bind to the promoters of numerous ethylene-responsive genes, including those involved in fruit ripening, leaf senescence, and various stress responses, coordinating the physiological changes associated with the gaseous hormone.

202. (A) Protein Phosphatases type 2C (PP2Cs).
The core signaling pathway for abscisic acid involves a double-negative regulatory mechanism. In the absence of the hormone, Protein

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the enzyme ACC synthase. The activity and expression of ACC synthase are tightly controlled by various developmental and environmental signals, ensuring that ethylene production is precisely timed during events like fruit ripening or wounding.

184. (A) Campesterol
Brassinosteroids are polyhydroxylated steroid hormones essential for plant growth and development. They are synthesized through a complex pathway that branches off from the general sterol biosynthetic route. The primary universal sterol precursor for brassinosteroid synthesis is campesterol. Campesterol undergoes a series of hydroxylations and oxidative steps to ultimately form brassinolide, the most biologically active member of the family.

185. (A) Linolenic acid
Jasmonic acid and its derivatives are important signaling molecules involved in plant defense and development. They are synthesized from unsaturated fatty acids released from membrane lipids. The primary precursor for the JA biosynthetic pathway is alpha-linolenic acid. This fatty acid undergoes a series of enzymatic transformations, starting with oxygenation by lipoxygenase, to produce the cyclic structure of jasmonic acid.

186. (A) Chloroplast
Early stages of the jasmonic acid biosynthetic pathway take place within the chloroplast. This includes the initial oxygenation of linolenic acid and the subsequent actions of allene oxide synthase and cyclase to form 12-oxo-phytodienoic acid. OPDA is then transported out of the chloroplast and into the peroxisome, where the final steps of JA synthesis, including beta-oxidation, occur.

187. (A) Inhibition of hypocotyl elongation, thickening of the hypocotyl, and exaggerated apical hook
The triple response is a classic physiological reaction of etiolated dicot seedlings to the presence of ethylene. It consists of three distinct morphological changes: inhibition of hypocotyl elongation, thickening or swelling of the hypocotyl, and development of an exaggerated apical hook. This response helps the seedling navigate obstacles as it pushes through the soil during early growth stages.

188. (A) Water deficit (drought stress)
Abscisic acid is often referred to as the stress hormone because of its central role in abiotic stress responses. The primary physiological trigger that upregulates ABA biosynthesis in plant leaves is water deficit. As leaf water potential drops, the expression of key biosynthetic enzymes is induced, leading to a rapid increase in ABA levels that triggers stomatal closure.

189. (A) The de-etiolated (det2) mutant
The de-etiolated mutant of Arabidopsis is a classic example of a plant with a defect in brassinosteroid biosynthesis. These mutants exhibit a severe dwarf phenotype, small dark green leaves, and reduced fertility. Because the defect is specifically in the production of the hormone, the exogenous application of brassinosteroids can completely rescue the mutant phenotype, restoring normal growth and development.

190. (B) II, III, I
The production of the gaseous plant hormone ethylene follows a strictly regulated biochemical pathway starting from a common amino acid.
The process begins with the synthesis of S-adenosylmethionine from methionine.
In the second step, the enzyme ACC synthase converts SAM into 1-aminocyclopropane-1-carboxylic acid.
Finally, the enzyme ACC oxidase catalyzes the conversion of ACC into the active ethylene gas.

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191. (A) Induction and maintenance of seed dormancy
Abscisic acid is the most critical hormone involved in the regulation of seed development. Its most unique and vital function is the induction and maintenance of seed dormancy during the maturation phase. High levels of ABA prevent the seed from germinating prematurely while still on the mother plant, ensuring that the embryo remains quiescent until appropriate environmental cues are received.

192. (A) Primary root elongation
While jasmonates are well-known for roles in plant defense and reproductive development, they also significantly influence vegetative growth. One of the most characteristic effects of jasmonic acid is the potent inhibition of primary root elongation. This response is often used in laboratory assays to identify mutants with

This leads to the transfer of electrons to oxygen, producing superoxide, hydrogen peroxide, and singlet oxygen, which damage machinery.

212. (A) Increase in the degree of unsaturation of fatty acids
To survive cold stress, plants must maintain the fluidity of cellular membranes, which otherwise become rigid and prone to leaking. This is achieved through the biochemical modification of membrane lipids, specifically by increasing the degree of unsaturation of the fatty acid tails. By incorporating more double bonds, the plant ensures that the membrane remains functional and flexible at low temperatures.

213. (A) Glutathione
Phytochelatins are small, sulfur-rich peptides that play a crucial role in detoxifying heavy metals. These molecules are synthesized enzymatically from the tripeptide glutathione by the enzyme phytochelatin synthase. Because they are derived from glutathione, the production of phytochelatins is directly dependent on the plant's sulfur status. Once formed, they chelate heavy metal ions for sequestration into the vacuole.

214. (A) Catalase
Catalase is a highly efficient antioxidant enzyme that catalyzes the disproportionation of hydrogen peroxide into water and molecular oxygen. In plant cells, catalase is primarily localized within the peroxisomes. Its activity is essential for removing the hydrogen peroxide produced during photorespiration and the beta-oxidation of fatty acids. By preventing peroxide accumulation, catalase protects the cell from damaging radicals.

215. (A) Their expression is strictly induced only at temperatures above 45°C.
Heat Shock Proteins are molecular chaperones that plants produce to cope with high-temperature stress. The statement that their expression is strictly induced only above 45°C is incorrect. While their levels increase dramatically at high temperatures, many HSPs are expressed at lower temperatures or constitutively to assist in normal protein folding and cellular maintenance during growth.

216. (A) Cytosolic calcium (Ca^{2+})
Cytosolic calcium is a universal secondary messenger in plants that links the perception of environmental stimuli to cellular responses. Abiotic stresses trigger rapid and characteristic increases in the concentration of cytosolic calcium. These calcium signatures are recognized by specialized calcium-binding proteins, which then activate downstream signaling cascades, including protein kinases and transcription factors, to initiate the stress response.

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217. (A) Rapid, localized programmed cell death at the site of pathogen infection
The hypersensitive response is a rapid and localized defense mechanism employed by plants to restrict the spread of biotrophic pathogens. It is characterized biochemically and cytologically by programmed cell death at the site of infection. By sacrificing a small number of cells, the plant creates a zone of dead tissue that deprives the pathogen of nutrients and prevents invasion.

218. (A) PAMP-Triggered Immunity (PTI)
PAMP-Triggered Immunity represents the first layer of the plant's active defense system. It is initiated when plant pattern recognition receptors detect conserved Pathogen-Associated Molecular Patterns, such as bacterial flagellin or fungal chitin. This perception triggers a suite of basal defense responses, including an oxidative burst and cell wall reinforcement, which are often sufficient to stop non-adapted pathogens.

219. (A) Nucleotide-binding site and Leucine-rich repeats (NBS-LRR)
To overcome basal defenses, many pathogens deliver effector proteins into the plant cell. In response, plants have evolved Resistance proteins that can specifically recognize these effectors. The majority of these R proteins belong to the NBS-LRR class. Recognition of an effector by an NBS-LRR protein triggers Effector-Triggered Immunity, a robust defense response often including the hypersensitive response.

220. (C) P-III, Q-IV, R-II, S-I
Plants utilize a diverse array of chemical and structural components to defend themselves against pathogen attacks.
Defense Molecules:
P. Phytoalexins are antimicrobial compounds synthesized de novo after infection.

Q. Salicylic acid acts as the primary systemic signal for SAR.
R. Chitinases are enzymes that directly degrade fungal cell walls.
S. Callose is a beta-1,3-glucan polymer for cell wall reinforcement.

221. (A) Isoflavonoids (e.g., pisatin, glyceollin)
Phytoalexins are low-molecular-weight antimicrobial compounds that plants synthesize in response to infection. Different plant families typically produce distinct structural classes of these molecules. The Leguminosae family is characterized by the production of isoflavonoids, such as pisatin in joys and glyceollin in soybeans. these compounds are highly effective at inhibiting the growth of a range of fungal pathogens.

222. (A) NPR1 (Non-expresser of PR genes 1)
Systemic Acquired Resistance is a broad-spectrum resistance that develops throughout a plant following an initial localized infection. This response is mediated by the hormone salicylic acid. The NPR1 protein is the master regulator of SAR. Upon the accumulation of salicylic acid, NPR1 undergoes a redox-mediated change that allows it to move into the nucleus and activate defense genes.

223. (A) NAD(P)H oxidase (RBOH)
The oxidative burst is one of the earliest responses in plant-pathogen interactions, involving the rapid production of reactive oxygen species. The enzyme complex primarily responsible for this burst is the plasma membrane-bound NADPH oxidase, also known as RBOH. This enzyme transfers electrons from NADPH to molecular oxygen to produce the superoxide anion, which initiates a cascade of defense-related signaling.

224. (A) Triggered by beneficial rhizobacteria; mediated by jasmonic acid and ethylene
Induced Systemic Resistance is a form of systemic defense that is uniquely triggered by beneficial soil microbes. Unlike SAR, which is mediated by salicylic acid, ISR relies on the signaling pathways of jasmonic acid and ethylene. ISR does not typically involve the induction of PR genes but instead primes the plant to respond more rapidly to future attacks.

225. (A) Hydrolysis of beta-1,3-glucans and chitin
Many Pathogenesis-Related proteins exhibit direct antimicrobial activity by degrading structural components of pathogens. PR-2 proteins are beta-1,3-glucanases, while PR-3 proteins are chitinases. Together, these enzymes can hydrolyze the beta-glucans and chitin that make up the cell walls of many fungi. This action inhibits fungal growth and releases oligosaccharides that further act as signals to amplify defense.

226. (A) Signaling molecules and wall cross-linking agents.
During the hypersensitive response, reactive oxygen species serve multiple critical functions beyond their direct toxicity. They act as essential signaling molecules that help coordinate programmed cell death. Additionally, ROS are required for the oxidative cross-linking of cell wall polymers, which strengthens the wall at the infection site to physically trap and contain the pathogen, preventing its further spread.

227. (A) Phytoanticipins are pre-formed inhibitory compounds present before infection, whereas phytoalexins are synthesized de novo post-infection.
Phytoanticipins and phytoalexins are both important chemical defenses, but they differ in their timing. Phytoanticipins are pre-formed inhibitory compounds already present in plant tissue before contact with a pathogen. In contrast, phytoalexins are synthesized only after the plant perceives an infection. Both groups contribute to the plant's overall ability to resist attack by various microorganisms in the environment.

228. (A) Systemin
In response to chewing by herbivores, plants generate systemic signals to induce defense in undamaged distant leaves. Systemin is an 18-amino acid peptide hormone found in solanaceous plants that acts as a major mobile signal. It is released from its precursor at the wound site and travels through the plant to trigger the synthesis of jasmonic acid.

229. (A) A highly branched polymer of alpha-1,4 linked glucose with alpha-1,6 branch points
Starch consists of two types of glucose polymers. Amylopectin is the major component and is characterized by a highly branched structure. It is composed of long chains of alpha-D-glucose residues linked by alpha-1,4 glycosidic bonds, with frequent branch points formed by alpha-1,6 glycosidic bonds. This branching pattern allows

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for efficient packing of starch molecules within specialized plastids.

230. (A) Chloroplast stroma
In a photosynthetic leaf cell, starch is primarily synthesized and transiently stored during the day within the chloroplast stroma. This transitory starch is produced directly from the products of the Calvin cycle. At night, this starch is broken down and exported from the chloroplast to support the energy and carbon needs of the rest of the plant.

231. (A) ADP-glucose
The biosynthesis of starch in the plastid requires an activated form of glucose as a substrate for the enzyme starch synthase. ADP-glucose is the specific nucleotide sugar utilized for this purpose. It is synthesized from glucose-1-phosphate and ATP by the enzyme ADP-glucose pyrophosphorylase. This reaction is a key regulatory step that controls the rate of starch production.

232. (A) Beta-D-glucose, beta-1,4 linkages
Cellulose is the most abundant organic polymer on Earth and the principal structural component of the plant cell wall. It is a linear, unbranched polymer composed of beta-D-glucose monomers. These monomers are linked together by beta-1,4 glycosidic bonds. Multiple cellulose chains associate through extensive hydrogen bonding to form strong, crystalline microfibrils that provide the mechanical strength and rigidity.

233. (A) At the plasma membrane by the Cellulose Synthase Complex (CSC)
Unlike starch, which is synthesized inside plastids, the synthesis of cellulose occurs strictly at the plasma membrane. This process is carried out by the Cellulose Synthase Complex, often seen as rosettes. The complex takes UDP-glucose from the cytosol and polymerizes the glucose chains directly into the extracellular space, where they assemble into cellulose microfibrils that strengthen the wall.

234. (A) Glucose and Fructose
Sucrose is the primary form in which carbohydrates are transported through the phloem from source leaves to sink tissues in most plants. It is a non-reducing disaccharide, meaning that the glycosidic bond is formed between the anomeric carbons of its two component monosaccharides. Specifically, sucrose consists of one molecule of glucose and one molecule of fructose.

235. (A) Sucrose-phosphate synthase (SPS)
The synthesis of sucrose occurs in the cytosol and is highly regulated to balance carbon export. Sucrose-phosphate synthase is the key enzyme that catalyzes the synthesis of sucrose-6-phosphate from UDP-glucose and fructose-6-phosphate. This reaction is irreversible and represents a major control point in the sucrose biosynthetic pathway, influenced by factors like light, metabolites, and enzyme phosphorylation status.

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236. (A) Homogalacturonan (HG)
Pectins are complex, acidic polysaccharides that are major components of the primary cell wall. Homogalacturonan is the most abundant pectic polymer, consisting of a linear chain of alpha-1,4 linked galacturonic acid residues. The physical properties of HG are crucial for cell-cell adhesion and wall porosity, and they are significantly modified by enzymatic processes during plant growth and development.

237. (A) They remove methyl groups, exposing carboxyl groups that can cross-link via calcium ions to form rigid gels.
The properties of homogalacturonan are influenced by its degree of methylesterification. Pectin methylesterases remove methyl groups from galacturonic acid residues, exposing negatively charged carboxyl groups. These groups can then interact with divalent calcium ions to form cross-links. This creates a rigid gel structure that hardens the cell wall and reduces its extensibility, thereby regulating cell expansion.

238. (A) Central vacuole
Fructans are polymers of fructose that serve as alternative water-soluble storage carbohydrates in many plant families. Unlike starch, which is stored in plastids, fructans are typically synthesized and stored within the central vacuole of the cell. This location allows them to be quickly mobilized when needed and may also play a role in protecting against drought and cold stress.

239. (A) Sucrose synthase
Sucrose synthase is a reversible enzyme that plays a vital role in sink tissues, where it primarily

258. (A) Methionine
Glucosinolates are synthesized from various amino acids through a series of complex enzymatic reactions. For the production of aliphatic glucosinolates, which are common in plants like Arabidopsis and broccoli, the primary amino acid precursor is methionine. Methionine often undergoes several rounds of chain elongation before entering the core biosynthetic pathway, resulting in a wide array of aliphatic side chains.

259. (A) Tryptophan
Indolic glucosinolates are a specific class of these defensive metabolites that are derived from the amino acid tryptophan. These compounds are widely found in members of the Brassicaceae family. Their biosynthesis is tightly regulated and can be induced by various stress signals, including wounding. The breakdown products of indolic glucosinolates have unique biological properties and play roles in defense.

260. (A) Indole-3-acetic acid (Auxin)
The degradation of specific indolic glucosinolates can yield biologically active molecules that influence plant growth. Under certain conditions, the breakdown of these compounds can lead to the production of indole-3-acetonitrile, which can then be converted into the plant hormone indole-3-acetic acid. this provides a link where a chemical defense system can also serve as a source of growth hormone.

261. (A) Idioblasts or Myrosin cells
The physical separation of glucosinolates and their degrading enzyme myrosinase is essential for plant survival. Specialized plant cells known as idioblasts or myrosin cells are documented as the primary storage sites for the myrosinase enzyme. These cells keep the enzyme isolated from the vacuolar glucosinolates located in adjacent cells until tissue damage disrupts the internal cellular organization of the tissue.

262. (A) The system relies on light-induced activation of myrosinase rather than tissue damage.
The "mustard oil bomb" is a highly effective chemical defense system, but the statement that it relies on light-induced activation of myrosinase is incorrect. The activation of the system is strictly dependent on tissue damage, such as that caused by a chewing insect, which brings pre-formed glucosinolates and myrosinase into contact. The triggering event is always physical disruption of cells.

263. (A) Glucoraphanin
Sulforaphane is a well-known isothiocyanate with significant health-promoting properties that is derived from the hydrolysis of a specific glucosinolate found abundantly in broccoli. This precursor glucosinolate is called glucoraphanin. When broccoli tissue is crushed or chewed, myrosinase converts glucoraphanin into sulforaphane. In addition to plant defense, sulforaphane has been studied for its potential anti-cancer and antioxidant effects in humans.

264. (A) Erucic acid and Glucosinolates
Canola oil is a high-quality vegetable oil derived from specific rapeseed varieties. These varieties were developed through traditional breeding to significantly reduce the levels of two undesirable compounds: erucic acid in the oil and glucosinolates in the remaining meal. Reducing erucic acid improves heart health, while lowering glucosinolates makes the meal more suitable as a high-protein livestock feed ingredient.

265. (A) Imbibition (uptake of water)
The process of seed germination strictly begins with the physical phenomenon of imbibition, which is the rapid uptake of water by the dry seed. This water uptake is driven by the very low water potential of dry seed components. Imbibition is essential because it rehydrates cellular tissues, activates dormant enzymes, and triggers the metabolic processes necessary for growth.

266. (A) Passive water uptake driven by seed matric potential.
Imbibition follows a characteristic triphasic curve of water uptake. Phase I is characterized by the rapid and passive uptake of water driven primarily by the seed's matric potential. This phase is entirely physical and can occur even in dead seeds. During Phase I, the seed expands significantly, and internal structures are rehydrated, setting the stage for subsequent metabolic reactivation.

267. (A) Active cellular metabolism, DNA repair, and mitochondrial reorganization commence.
Phase II of imbibition, often called the lag phase, is a period where water uptake reaches a plateau and becomes very slow. Despite the

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processed by a second P450 enzyme to form the alpha-hydroxynitrile precursor.

249. (A) HCN acts as an attractant for pollinating insects.
While cyanogenic glycosides serve as effective deterrents against many generalist herbivores due to the release of toxic cyanide, the statement that HCN acts as an attractant for pollinating insects is incorrect. Cyanide is a general toxin, and its release is usually timed with tissue damage to repel predators. Pollinator attraction is typically mediated by volatile organic compounds and floral colors.

250. (B) III, IV, I, II
The metabolic pathway for the synthesis of cyanogenic glycosides is a precise sequence of enzymatic steps that transform primary amino acids into defensive chemicals.
The process starts with a precursor amino acid, which is first converted into an aldoxime intermediate.
A second enzyme then transforms the aldoxime into an alpha-hydroxynitrile.
Finally, a glucosyltransferase adds a sugar moiety.

251. (A) UDP-glucosyltransferase (UGT)
The final step in the biosynthesis of a cyanogenic glycoside is catalyzed by a UDP-glucosyltransferase. This enzyme transfers a glucose molecule from UDP-glucose to the reactive aglycone. This glycosylation is essential because it stabilizes the molecule, making it non-toxic and allowing it to be safely stored in the plant's vacuole until it is needed for defense upon tissue damage.

252. (A) Rosaceae
Amygdalin is a well-known cyanogenic glycoside found abundantly in the seeds of many species within the Rosaceae family, including almonds, apricots, and peaches. The presence of amygdalin gives these seeds a characteristic bitter taste and provides a chemical defense against seed predators. When seeds are crushed, they release cyanide, which can be toxic if consumed in large quantities by animals.

253. (A) Brassicales
Glucosinolates are a unique class of sulfur- and nitrogen-containing secondary metabolites primarily associated with plants in the order Brassicales. This order includes the large Brassicaceae family, which contains important crops like broccoli and cabbage. Glucosinolates are a defining chemical characteristic of these plants, providing them with their characteristic pungent flavors and a highly effective defense system against generalist herbivores.

254. (A) A beta-D-thioglucose group, a sulfonated oxime, and an amino acid-derived side chain
The core chemical structure of a glucosinolate is highly conserved across species. It consists of a beta-D-thioglucose group, a sulfonated oxime group, and a variable side chain derived from an amino acid. The diversity of glucosinolates is primarily due to different amino acids used and subsequent modifications to the side chain, which influence the activity of breakdown products.

255. (A) Myrosinase (Thioglucosidase)
Myrosinase is the endogenous enzyme responsible for the hydrolysis of glucosinolates. Under normal conditions, myrosinase is physically separated from its glucosinolate substrates. However, when plant tissue is damaged by chewing, the enzyme and substrate come into contact. Myrosinase then cleaves the glucose moiety, triggering a spontaneous rearrangement that leads to the formation of various toxic and pungent sulfur compounds.

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256. (A) Isothiocyanate
Upon hydrolysis of a glucosinolate by the enzyme myrosinase, the unstable aglycone intermediate spontaneously undergoes a rearrangement. At neutral pH, the most common and predominant product formed is an isothiocyanate. These compounds are responsible for the pungent taste and smell of mustard. Isothiocyanates are highly reactive and act as potent deterrents against herbivores and antimicrobial agents against pathogens.

257. (A) Highly acidic pH and presence of ESP
The type of breakdown product formed from a glucosinolate depends on the presence of specific specifier proteins. The formation of nitriles typically occurs in the presence of Epithiospecifier Protein and under acidic pH conditions. These proteins direct the spontaneous rearrangement of the aglycone away from the default isothiocyanate pathway, allowing the plant to produce a different suite of chemicals.

softened through natural processes or artificial methods like scarification.

296. (A) By exposure to unfavorable environmental conditions post-dispersal
Secondary dormancy is an adaptive trait that allows mature, non-dormant seeds to re-enter a state of dormancy if they are exposed to unfavorable environmental conditions after dispersal. Factors such as extreme temperatures or prolonged darkness can trigger this response. Secondary dormancy ensures that the seed does not germinate at a time when the resulting seedling would have a low survival chance.

297. (A) It acts as a key positive regulator in the ABA signaling network to enforce dormancy.
ABI3 is a master transcription factor that plays a central role in the ABA signaling network within developing and mature seeds. It acts as a key positive regulator that enforces the dormancy program and promotes the synthesis of seed storage proteins and desiccation tolerance factors. By mediating the response to ABA, ABI3 ensures the seed remains dormant until correct conditions.

298. (A) Decreasing ABA synthesis and increasing GA synthesis
Light promotes the germination of many small seeds by shifting internal hormonal balance in favor of growth. When seeds perceive red light, the active form of phytochrome directly regulates genes involved in hormone metabolism. Active phytochrome leads to a decrease in ABA levels by inhibiting its synthesis and promoting its degradation, while simultaneously increasing bioactive GA levels by upregulating biosynthetic enzymes.

299. (A) GA
In many endospermic seeds, the radicle must overcome the physical resistance of the surrounding endosperm tissue to protrude and complete germination. Gibberellic acid is the hormone responsible for facilitating this process. GA promotes the synthesis and secretion of various cell-wall-remodeling enzymes into the endosperm. These enzymes weaken the cell walls in the path of the radicle, allowing emergence through softened tissue.

300. (A) The depth of primary dormancy established during seed maturation
The DELAY OF GERMINATION 1 protein is a major master regulator of primary seed dormancy. The amount of DOG1 protein that accumulates during seed maturation on the mother plant is tightly and positively correlated with the depth or intensity of primary dormancy in the mature seed. High DOG1 levels ensure that the seed remains dormant for a longer period of time.

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lack of outward changes, this is a time of intense physiological activity. During Phase II, the seed re-establishes active metabolism, including the initiation of DNA repair, mitochondrial reorganization, and synthesis of new proteins and mRNA required.

268. (A) The radicle protrudes through the seed coat/ endosperm.
In plant physiology, the completion of the germination process is visibly and definitively marked by the emergence of the radicle through the seed coat or endosperm. This event signals that the embryo has successfully transitioned from a quiescent state to active growth. Once the radicle has protruded, the process is considered finished, and subsequent growth is referred to as post-germination.

269. (A) Increase in turgor pressure driven by osmotically active solute generation
During Phase III of germination, physical protrusion of the radicle through the seed coat is primarily driven by expansion of existing cells in the radicle tip. This expansion is powered by a significant increase in turgor pressure. The plant generates osmotically active solutes, such as simple sugars and amino acids, which pull water into cells, creating the required hydrostatic pressure.

270. (A) Phytochrome
Many seeds are photoblastic, meaning they require a specific light signal to initiate germination. This process is mediated by the photoreceptor phytochrome. Phytochrome can exist in two interconvertible forms: inactive and active. Red light promotes germination by converting the inactive form to the active form. Once active, phytochrome triggers a signaling cascade that alters the balance of plant hormones.

271. (A) It reverses the effect of red light and inhibits germination by converting Pfr back to Pr.
In seeds that require light for germination, the effect of red light is completely reversible by subsequent exposure to far-red light. Far-red light converts the active form of phytochrome back to the inactive form. This prevents initiation of the germination signaling pathway. This photoreversibility is a classic characteristic of phytochrome-mediated responses and allows the seed to sense its environment.

272. (A) A period of moist, cold conditions
Stratification is an agricultural technique used to break seed dormancy and ensure uniform germination. It involves subjecting seeds to a period of moist, cold conditions. This process artificially mimics natural winter conditions that some seeds must experience before germinating in spring. Stratification leads to biochemical changes, such as a decrease in ABA and an increase in gibberellins, that promote growth.

273. (A) Glycolysis and fermentation
At the beginning of seed imbibition, mitochondria are not yet fully functional for oxidative phosphorylation. To generate initial ATP required for early metabolic reactivation, the seed relies on anaerobic pathways such as glycolysis and fermentation. These processes use stored sugars to provide a quick source of energy. As imbibition progresses, mitochondria are reorganized and take over as the primary site.

274. (A) Hypocotyl
In epigeal germination, the seedling exhibits a characteristic growth pattern where cotyledons are raised above the soil surface. This is achieved through rapid elongation of the hypocotyl, which is the part of the seedling axis below the cotyledons. The hypocotyl often forms a hook as it pushes through the soil, eventually straightening out to pull the cotyledons into light.

NODIA

275. (A) Epicotyl (or mesocotyl in cereals)
In hypogeal germination, the cotyledons remain below the soil surface throughout the early stages of seedling development. To propel the shoot out of the soil, the seedling relies on the rapid elongation of the epicotyl, which is the portion of the seedling axis above the cotyledons. This strategy protects the nutrient-rich cotyledons from surface predators and harsh environmental conditions.

276. (A) It synthesizes and secretes hydrolytic enzymes into the starchy endosperm.
The aleurone layer is a specialized tissue that surrounds the starchy endosperm in cereal grains. Its primary function during germination is to act as a metabolic factory. In response to signals from the embryo, aleurone cells synthesize and secrete a suite of hydrolytic enzymes into the endosperm. These enzymes are responsible for

breaking down stored starch and proteins for nutrients.

277. (A) Random endo-cleavage of alpha-1,4 glycosidic bonds in amylose and amylopectin
Mobilization of stored starch reserves in the cereal endosperm is primarily carried out by the enzyme alpha-amylase. This enzyme functions by performing random endo-cleavage of alpha-1,4 glycosidic bonds within amylose and amylopectin molecules. This process rapidly breaks down large, insoluble starch polymers into smaller, soluble dextrins and maltose. These products are then further hydrolyzed into glucose for energy.

278. (A) Lipase
Oilseed crops store large amounts of lipids as their primary energy reserve. During germination, these triglycerides are broken down through the action of the enzyme lipase. Lipase hydrolyzes the ester bonds between the glycerol backbone and the three fatty acid chains. The released fatty acids are then transported to the glyoxysomes to enter the beta-oxidation pathway and the glyoxylate cycle.

279. (A) Glyoxysomes
In germinating oilseeds, conversion of stored lipid reserves into mobile sucrose is an essential process. The unique biochemical reactions of the glyoxylate cycle take place within specialized organelles called glyoxysomes. These organelles contain the enzymes necessary to bypass the carbon-releasing steps of the traditional TCA cycle. This allows the plant to net-synthesize four-carbon compounds from two-carbon acetyl-CoA units.

280. (A) Isocitrate lyase and Malate synthase
The glyoxylate cycle is a specialized metabolic pathway that allows plants to convert fats into carbohydrates. Two enzymes are unique to this cycle and are absent in animals: isocitrate lyase and malate synthase. These enzymes allow the cycle to bypass the two decarboxylation steps of the TCA cycle. By avoiding carbon loss as CO_2, plants can convert lipids into succinate.

281. (A) Glyoxylate and Succinate
In the glyoxylate cycle, the enzyme isocitrate lyase catalyzes a key reaction where isocitrate is cleaved into two smaller products. These products are the two-carbon molecule glyoxylate and the four-carbon molecule succinate. Glyoxylate remains in the cycle to be combined with acetyl-CoA, while succinate is exported from the glyoxysome to the mitochondria, where it enters the gluconeogenesis pathway.

282. (A) PEP carboxykinase (PEPCK)
During gluconeogenesis in germinating seeds, the plant must convert non-carbohydrate precursors into sugars. A key committed step in this pathway is the conversion of oxaloacetate into phosphoenolpyruvate. This reaction is catalyzed by the enzyme PEP carboxykinase. This is an energy-requiring step that bypasses the irreversible reaction of pyruvate kinase, allowing carbon flow to be directed toward glucose and sucrose production.

283. (A) Protein storage vacuoles
Seeds store large amounts of specialized proteins as a source of nitrogen and sulfur for the developing seedling. During germination, these storage proteins are rapidly mobilized through the action of various proteases. This degradation process occurs primarily within specialized compartments called protein storage vacuoles. The proteins are broken down into component amino acids, which are then transported to growing parts.

284. (A) Phosphorus
Phytic acid is the major storage form of phosphorus in the seeds of many plants. It is typically found in the form of phytate salts, complexed with various minerals such as magnesium, calcium, and potassium. Storing phosphorus as phytic acid is an efficient way to pack this essential nutrient into a compact and stable form, ensuring it is available for growth.

285. (A) Phytase
To utilize the phosphorus stored as phytic acid, the germinating seed must first hydrolyze the phosphate groups from the inositol ring. This process is carried out by the enzyme phytase, which is synthesized de novo during early germination. Phytase activity releases inorganic phosphate and associated mineral cations, providing essential nutrients required for the synthesis of nucleic acids, phospholipids, and ATP.

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286. (A) They are transported to the growing embryonic axis to synthesize new proteins.
Hydrolysis of seed storage proteins generates a large pool of amino acids in the cotyledons or endosperm. The bulk of these amino acids is not oxidized for energy but is instead transported to the growing embryonic axis. Once they reach the shoot and root meristems, these amino acids are used as the primary building blocks for new structural proteins.

287. (A) Gluconeogenesis
During early seedling growth, especially in legumes, there can be a surplus of amino acids compared to the immediate needs for protein synthesis. To efficiently use these resources, the plant employs the gluconeogenesis pathway to convert the carbon skeletons of excess amino acids into sugars like sucrose. This process is essential for maintaining the energy balance and providing mobile carbohydrates.

288. (A) The scutellum
In the starchy endosperm of cereal grains, the breakdown of starch reserves yields simple sugars such as glucose and maltose. The scutellum is a specialized tissue, part of the embryo, that acts as a highly efficient absorptive organ. It is positioned directly against the endosperm and possesses specific transporters to take up the released sugars for transport to the embryonic axis.

289. (A) Abscisic acid (ABA)
Establishment of primary seed dormancy during maturation is a highly regulated developmental process. The phytohormone abscisic acid is the master regulator that induces and maintains this state of dormancy while the seed is still attached to the mother plant. High levels of ABA prevent the embryo from germinating prematurely and help the seed survive the dehydration process until shed.

290. (A) Gibberellic acid (GA)
The transition from a dormant seed to a germinating seed is fundamentally regulated by the dynamic antagonistic balance between two plant hormones: abscisic acid and gibberellic acid. ABA acts as a potent inhibitor of germination and maintains dormancy, while GA acts as a promoter that breaks dormancy and stimulates growth. The relative concentration of these hormones determines germination initiation.

291. (A) They rapidly decrease due to both leaching and active enzymatic catabolism.
When a seed is placed in favorable conditions for germination, the endogenous levels of the dormancy-promoting hormone ABA typically decrease rapidly. this reduction occurs through two main mechanisms: physical leaching of ABA out of the seed into surrounding water and active enzymatic catabolism within seed tissues. This drop in ABA removes the primary inhibition, allowing promotion by gibberellins.

292. (A) ABA 8'-hydroxylase
Enzymatic degradation of ABA is a critical step in breaking seed dormancy and starting germination. The primary enzyme responsible for this process is ABA 8'-hydroxylase, which converts active ABA into phaseic acid. Expression of genes encoding this enzyme is upregulated during seed imbibition, especially in response to environmental cues. This catabolism ensures that ABA levels fall sufficiently for germination.

293. (A) GA 3-oxidase
Initiation of radicle emergence during germination is preceded by a sharp increase in the levels of bioactive gibberellins. This increase is achieved through up-regulation of de novo GA biosynthesis, particularly the enzyme GA 3-oxidase. This enzyme catalyzes the final step in the formation of active GAs. The spike in active GA levels triggers genes involved in cell wall loosening.

294. (A) Vivipary
Vivipary is a phenomenon where seeds germinate precociously while still attached to the mother plant. This condition is classically seen in mutants that are deficient in the biosynthesis of or sensitivity to the hormone abscisic acid. Because ABA is essential for induction of dormancy and prevention of premature growth, its absence allows the embryo to bypass the dormant phase.

295. (A) Physical dormancy
Seed dormancy can be enforced by different mechanisms. Physical dormancy is caused by physical barriers that prevent uptake of water or exchange of gases, most commonly due to an impermeable seed coat. This type of dormancy is common in families like Fabaceae. To break physical dormancy, the seed coat must be

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catalyzes the cleavage of sucrose. In the presence of UDP, it breaks down sucrose into fructose and UDP-glucose. This reaction provides necessary substrates for several metabolic pathways, including cell wall biosynthesis. Sucrose synthase activity is a major determinant of sink strength.

240. (A) Fructose-1,6-bisphosphate → Fructose-6-phosphate → Sucrose-6-phosphate → Sucrose
The synthesis of sucrose in the plant cytosol follows a highly coordinated series of enzymatic reactions starting from triose phosphates exported from the chloroplast. First, two triose phosphates combine to form fructose-1,6-bisphosphate, which is dephosphorylated to fructose-6-phosphate. Subsequently, fructose-6-phosphate is combined with UDP-glucose to produce sucrose-6-phosphate. Finally, the phosphate group is removed to yield the sucrose.

241. (A) Cyanogenesis
Cyanogenesis is the process by which certain plants release toxic hydrogen cyanide gas as a defense mechanism. This chemical reaction occurs when plant tissues are damaged, bringing pre-formed cyanogenic glycosides into contact with specific degradative enzymes. The rapid release of cyanide serves as a potent deterrent because it is highly toxic to most aerobic organisms by inhibiting cellular respiration.

242. (A) Amino acids
The structural backbone of cyanogenic glycosides is derived entirely from the class of primary metabolites known as amino acids. Specifically, different plant species utilize different amino acids as the starting material. These amino acids undergo a series of specialized enzymatic transformations to form the aglycone core of the glycoside, linking primary nitrogen metabolism directly to chemical defense in plants.

243. (A) By physically separating the glycosides from their degradative enzymes
To prevent autotoxicity, plants that produce cyanogenic glycosides ensure that toxic HCN gas is only released when needed. They achieve this by physically separating the cyanogenic glycosides from their degradative enzymes at the cellular or tissue level. For example, the glycosides may be stored in the vacuole while the enzymes are in the cytosol, ensuring the system only activates.

244. (A) Beta-glucosidase and Hydroxynitrile lyase
Release of hydrogen cyanide from a cyanogenic glycoside is a two-step enzymatic process that occurs upon tissue damage. In the first step, a specific beta-glucosidase enzyme hydrolyzes the sugar moiety to form an unstable intermediate called a cyanohydrin. In the second step, the enzyme hydroxynitrile lyase catalyzes the breakdown of the cyanohydrin into a carbonyl compound and toxic cyanide.

245. (A) Linamarin and Lotaustralin
Cassava is a vital staple crop, but its roots and leaves contain significant levels of toxic cyanogenic glycosides. The two primary glycosides found in cassava are linamarin and its methyl derivative, lotaustralin. Linamarin accounts for about 95% of the total cyanogenic content. Processing techniques such as peeling and fermenting are necessary to release the cyanide and make the cassava safe.

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246. (A) It potently inhibits cytochrome c oxidase in the mitochondrial electron transport chain.
The immediate physiological mechanism by which released hydrogen cyanide causes toxicity is its potent inhibition of cellular respiration. Cyanide binds with high affinity to the iron atom in the heme group of cytochrome c oxidase, which is the terminal enzyme of the electron transport chain. This blocks the transfer of electrons to oxygen, effectively stopping ATP production and leading to death.

247. (A) Tyrosine
Dhurrin is a well-studied cyanogenic glycoside that is highly accumulated in the young seedlings of sorghum. Its biosynthesis is an excellent example of a specialized metabolic pathway. The direct biosynthetic precursor of dhurrin is the amino acid tyrosine. Through specialized enzymatic transformations, tyrosine is converted into dhurrin, which provides the sorghum seedling with chemical protection during its vulnerable stages.

248. (A) An oxime
The biosynthesis of cyanogenic glycosides involves the sequential action of two closely linked cytochrome P450 enzymes. The first P450 enzyme catalyzes the conversion of the precursor amino acid into an aldoxime intermediate. This step involves N-hydroxylation and decarboxylation of the amino acid. The aldoxime is then further

CHAPTER 09
Plant Molecular Biology

2016

1. What is the fundamental repeating structural unit of eukaryotic chromatin?
(A) Telomere
(B) Nucleosome
(C) Centromere
(D) Chromatid

2001

2. The C-value paradox specifically refers to the lack of correlation between an organism's biological complexity and what genomic feature?
(A) Number of chromosomes
(B) Number of protein-coding genes
(C) Frequency of crossing over
(D) Total haploid DNA content

2010

3. Which structural feature is highly conserved and characteristic of most land plant chloroplast genomes?
(A) Large inverted repeats separating single-copy regions
(B) Linear multipartite chromosomal DNA arrangements
(C) Complete absence of all intergenic spacer regions
(D) Polyadenylated circular extrachromosomal plasmids

2018

4. Plant mitochondrial genomes generate subgenomic circles primarily through which molecular mechanism?
(A) Non-homologous end joining of double-strand breaks
(B) RNA interference-mediated degradation of transcripts
(C) Homologous recombination across large repeat sequences
(D) Retrotransposition of conserved nuclear elements

2004

5. The TATA box in eukaryotic nuclear promoters is typically located at what approximate position relative to the transcription start site?
(A) Upstream at position -250
(B) Upstream at position -30
(C) Downstream at position +30
(D) Downstream at position +100

2006

6. During eukaryotic mRNA processing, what is the sequence of the highly conserved polyadenylation signal?
(A) UAGUAA
(B) GGGCCC
(C) CCUCAA
(D) AAUAAA

2019

7. Which trans-acting factor specifically recognizes and binds to enhancer sequences to upregulate gene expression?
(A) RNA polymerase core enzyme
(B) Transcriptional activator
(C) Spliceosome complex
(D) General transcription factor TFIID

2015

8. Tissue-specific gene expression is most commonly driven by which regulatory component?
(A) Universal core promoters
(B) Identical translational elongation rates
(C) Distinct enhancer or silencer elements
(D) Poly-A tail length variations

2003

9. In chloroplasts, the Plastid-Encoded Polymerase (PEP) recognizes promoters that strongly resemble which type of promoters?
(A) Eukaryotic RNA polymerase II promoters
(B) Archaeal transcription factor binding sites
(C) Viral reverse transcriptase origins
(D) Bacterial sigma-70 type promoters

2009

10. Consider the following statements regarding Cytoplasmic Male Sterility (CMS) in plants:
I. It is universally caused by mutations in nuclear genes.
II. It is associated with chimeric open reading frames in the mitochondrial genome.
III. Nuclear restorer (Rf) genes can suppress the male sterile phenotype.

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Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) II only

2008

11. The ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) holoenzyme consists of small and large subunits. Which genome encodes the large subunit (rbcL)?
(A) Nuclear genome
(B) Chloroplast genome
(C) Mitochondrial genome
(D) Endoplasmic reticulum

2018

12. In the context of biological nitrogen fixation, which gene cluster codes for the structural components of the nitrogenase enzyme?
(A) nod genes
(B) fix genes
(C) nif genes
(D) sym genes

2008

13. Which epigenetic modification is generally associated with transcriptional silencing and heterochromatin formation in plants?
(A) Histone acetylation
(B) DNA demethylation
(C) Histone H3 serine phosphorylation
(D) DNA methylation at specific cytosine residues

2001

14. Which methodology is a core component of functional genomics rather than structural genomics?
(A) Constructing a physical map of a chromosome
(B) Sequencing the complete DNA genome
(C) Identifying microsatellite loci locations
(D) Generating transcriptomic profiles using microarrays

2006

15. Illumina high-throughput sequencing primarily relies on which core biochemical principle?
(A) Sequencing by synthesis with reversible terminators
(B) Single-molecule real-time synthesis of DNA
(C) Current displacement across a protein nanopore
(D) Controlled chemical cleavage of DNA strands

2008

16. The SOS (Salt Overly Sensitive) signaling pathway in plants primarily regulates cellular homeostasis of which specific ion during salinity stress?
(A) Calcium
(B) Potassium
(C) Sodium
(D) Chloride

2011

17. In plant signal transduction, what is the primary role of a kinase cascade?
(A) To amplify the signal via successive phosphorylation events
(B) To degrade incoming ligand molecules
(C) To transport secondary messengers out of the cell
(D) To directly inhibit gene transcription at the promoter

2013

18. Which plant hormone mechanism heavily relies on the degradation of AUX/IAA repressor proteins via the ubiquitin-proteasome system?
(A) Auxin signaling
(B) Gibberellin signaling
(C) Cytokinin signaling
(D) Ethylene signaling

2002

19. MicroRNAs (miRNAs) in plants primarily regulate target gene expression through which mechanism?
(A) Enhancing transcription initiation
(B) Promoting translation factor assembly
(C) Directing mRNA cleavage or translational repression
(D) Inducing DNA double-strand breaks

2009

20. Consider the following statements regarding the RNA interference (RNAi) pathway:
I. Dicer enzymes cleave double-stranded RNA into short interfering RNAs.
II. Argonaute proteins are the catalytic components of the RISC complex.
III. RNAi always results in gene upregulation.
IV. Small RNAs guide the RISC complex to complementary target RNAs.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, III and IV
(C) II and III
(D) I and IV

NODIA

2005

21. Which type of molecular marker is based on the amplification of arbitrary genomic sequences using short, non-specific primers?
(A) RFLP
(B) RAPD
(C) SSR
(D) SNP

2025

22. In Marker-Assisted Selection (MAS), what is the most critical requirement for a molecular marker to be effective?
(A) It must be located on a completely different chromosome from the trait.
(B) It must exhibit no polymorphism between the parents.
(C) It must only amplify non-coding repetitive DNA.
(D) It must be tightly linked to the target gene or quantitative trait locus.

2002

23. A typical eukaryotic nucleosome core particle wraps approximately how many base pairs of DNA?
(A) 50 base pairs
(B) 147 base pairs
(C) 300 base pairs
(D) 1000 base pairs

2002

24. Which repetitive element class utilizes a copy-and-paste mechanism involving an RNA intermediate?
(A) DNA transposons
(B) Miniature Inverted-repeat Transposable Elements (MITEs)
(C) Retrotransposons
(D) Centromeric satellite repeats

2013

25. The inverted repeat (IR) regions of the chloroplast genome typically contain the genes encoding for what type of RNA?
(A) Messenger RNA
(B) Transfer RNA
(C) Ribosomal RNA
(D) Micro RNA

2012

26. Which phenomenon describes the post-transcriptional conversion of specific cytidine (C) residues to uridine (U) in plant mitochondrial transcripts?
(A) Alternative splicing
(B) RNA polyadenylation
(C) DNA methylation
(D) RNA editing

2013

27. The 5' untranslated region (5' UTR) of a typical eukaryotic nuclear gene primarily functions to regulate what process?
(A) Translation initiation and efficiency
(B) Intron removal
(C) Transcription termination
(D) Protein degradation

2013

28. Which component of the spliceosome is responsible for recognizing the 5' splice site during eukaryotic pre-mRNA processing?
(A) U2 snRNP
(B) U4 snRNP
(C) U1 snRNP
(D) U6 snRNP

2025

29. Trans-acting transcription factors typically possess structural domains such as zinc fingers or leucine zippers. What is the primary function of these specific domains?
(A) Ligand binding
(B) ATP hydrolysis
(C) Nuclear export
(D) DNA sequence recognition and binding

2018

30. Consider the following statements about specialized promoter targeting in plants:
I. Promoters can confine gene expression to root specific tissues.
II. Constitutive promoters are active only under stress conditions.
III. Tissue-specific promoters utilize unique cis-regulatory motifs.
IV. Floral organ identity relies on highly targeted expression networks.
V. Synthetic promoters can combine multiple specific cis-elements.
Which of the above statement(s) is/are correct?
(A) I, II, III and IV
(B) I, III, IV and V
(C) I, II and V
(D) II, III and IV

2004

31. Nuclear-Encoded Polymerase (NEP) in plastids typically transcribes which category of chloroplast genes early in plant development?
(A) Photosynthetic apparatus genes

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(B) Housekeeping genes and ribosomal proteins
(C) Starch degradation genes
(D) Cytoplasmic stress response genes

2014

32. In the CMS systems, nuclear restorer (Rf) genes predominantly encode which class of proteins that process mitochondrial transcripts?
(A) Kinases
(B) Ubiquitin ligases
(C) Heat shock proteins
(D) Pentatricopeptide repeat (PPR) proteins

2008

33. The precise stoichiometric balance of Rubisco subunits requires tight coordination between which two cellular compartments?
(A) Nucleus and chloroplast
(B) Nucleus and vacuole
(C) Chloroplast and mitochondria
(D) Mitochondria and peroxisome

2023

34. Which specific nodulation (nod) gene product serves as the primary sensor for plant-secreted flavonoids in the rhizobium-legume symbiosis?
(A) NodA
(B) NodC
(C) NodD
(D) NodF

2022

35. Histone acetyltransferases (HATs) typically catalyze modifications that lead to what change in chromatin structure?
(A) Relaxation into transcriptionally active euchromatin
(B) Condensation into dense heterochromatin
(C) Complete removal of histones from DNA
(D) Irreversible degradation of nucleosomes

2025

36. Which approach relies on introducing specific mutations or targeted gene deletions to infer a gene's biological role?
(A) Transcriptomics
(B) Proteomics
(C) Structural mapping
(D) Knockout line validation

2002

37. Which high-throughput sequencing platform generates exceptionally long reads by utilizing zero-mode waveguides?
(A) Illumina MiSeq
(B) PacBio SMRT sequencing
(C) Sanger Sequencing
(D) Solid sequencing

2024

38. Late Embryogenesis Abundant (LEA) proteins primarily confer tolerance against which form of abiotic stress?
(A) Heavy metal toxicity
(B) Water deficit (drought)
(C) Pathogen infection
(D) Hypoxia

2002

39. In plant signal transduction pathways, heterotrimeric G-proteins typically dissociate into which components upon activation?
(A) Alpha subunit and beta-gamma dimer
(B) Two alpha units and one beta unit
(C) Gamma subunit and alpha-beta dimer
(D) Three independent monomers

2024

40. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : The degradation of repressor proteins is a common regulatory theme in multiple plant hormone signaling pathways.
Reason (R) : Phytohormones such as auxin and gibberellin utilize ubiquitin-proteasome systems to remove transcriptional repressors like AUX/IAA and DELLA.
Which of the above statement(s) is/are correct?
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

NODIA

2015

41. Plant microRNAs are typically synthesized as long primary transcripts (pri-miRNAs) by which nuclear enzyme?
(A) RNA Polymerase II
(B) RNA Polymerase I
(C) RNA Polymerase III
(D) DNA Polymerase delta

2013

42. In the systemic acquired silencing phenomenon of RNA interference, what molecule is believed to act as the mobile silencing signal traversing plasmodesmata?
(A) Double-stranded DNA fragments
(B) Entire RISC complexes

(C) Long un-spliced mRNA molecules
(D) Small interfering RNAs (siRNAs)

2010

43. Simple Sequence Repeats (SSRs) are highly favored in plant genetic mapping because they typically exhibit which trait?
(A) Codominant inheritance
(B) Dominant inheritance
(C) Complete absence of polymorphism
(D) Instability during replication

2001

44. The identification of quantitative trait loci (QTLs) requires the integration of marker genotypic data with what other distinct dataset?
(A) Proteomic mass spectrometry data
(B) Intron retention profiles
(C) High-density phenotypic evaluation data
(D) Telomere length variations

2001

45. Which specific core histone protein is NOT part of the nucleosome octamer, but rather binds to the linker DNA?
(A) H1
(B) H2A
(C) H2B
(D) H3

2021

46. The highly repetitive elements found predominantly near plant centromeres and telomeres are classified as what type of sequence?
(A) Single-copy structural genes
(B) Long terminal repeat retrotransposons exclusively
(C) Conserved promoter boxes
(D) Tandem satellite repeats

2018

47. Which statement accurately describes the typical arrangement of a plastome (chloroplast genome)?
(A) A linear double-stranded RNA
(B) A circular double-stranded DNA molecule
(C) A linear single-stranded DNA
(D) A circular single-stranded RNA molecule

2012

48. Due to frequent recombination events, the mitochondrial genome of plants is best structurally characterized by which term?
(A) Monopartite rigid circle
(B) Strictly linear multimer
(C) Multipartite variable structure
(D) Diploid homomeric complex

2018

49. The precise boundary separating an exon and an intron at the 5' end of an intron is strictly defined by which highly conserved dinucleotide in pre-mRNAs?
(A) AG
(B) CA
(C) TT
(D) GT

2005

50. Match the sequencing platform in List I with its core fundamental chemistry in List II:
List I : (Sequencing Platform)
P. Sanger
Q. Illumina
R. PacBio
S. Oxford Nanopore
List II : (Chemistry)
1. Protein channel disruption
2. Reversible dye terminators
3. Zero-mode waveguide SMRT
4. Dideoxynucleotide chain termination
(A) P-4, Q-2, R-3, S-1
(B) P-1, Q-4, R-2, S-3
(C) P-2, Q-3, R-1, S-4
(D) P-3, Q-1, R-4, S-2

2016

51. The addition of a 7-methylguanosine cap to eukaryotic pre-mRNA is primarily catalyzed by enzymes targeting which extremity of the transcript?
(A) The 3' hydroxyl end
(B) The 5' triphosphate end
(C) Internal adenine residues
(D) The polyadenylation tail

2005

52. Cis-regulatory elements such as enhancers are distinct from typical promoter regions because they possess which unique property?
(A) They are transcribed into functional proteins.
(B) They consist exclusively of GC-rich inverted repeats.
(C) They function independently of orientation or distance from the start site.
(D) They bind strictly to RNA polymerase without intermediate factors.

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2011

95. The non-coding sequences that interrupt the open reading frames of eukaryotic nuclear genes are defined as:
(A) Promoters
(B) Exons
(C) Introns
(D) Enhancers

2002

96. During nuclear mRNA capping, the guanosine nucleotide is connected to the nascent transcript via an unusual structural linkage. What is this specific linkage?
(A) 3'-5' phosphodiester bond
(B) 5'-5' triphosphate linkage
(C) Peptide bond
(D) Disulfide bridge

2010

97. The interaction between basal general transcription factors and distally bound specific transcription factors is typically mediated by a massive multiprotein complex known as:
(A) The Mediator complex
(B) The Spliceosome
(C) The Proteasome
(D) The Exosome

2009

98. An endogenous promoter that drives gene expression uniformly across virtually all cell types and developmental stages is classified as a:
(A) Inducible promoter
(B) Constitutive promoter
(C) Tissue-specific promoter
(D) Synthetic minimal promoter

2008

99. The Plastid-Encoded RNA Polymerase (PEP) requires additional nuclear-encoded proteins to achieve full transcriptional specificity. What are these auxiliary proteins called?
(A) Sigma factors
(B) Rho termination factors
(C) Reverse transcriptases
(D) Helicases

2016

100. Match the phytohormone in List I with its corresponding signaling repressor protein in List II:
List I : (Phytohormone)
P. Auxin
Q. Gibberellin
R. Jasmonic Acid
S. Brassinosteroid
List II : (Repressor Protein)
1. DELLA
2. JAZ
3. BIN2
4. AUX/IAA
(A) P-4, Q-1, R-2, S-3
(B) P-1, Q-4, R-3, S-2
(C) P-4, Q-2, R-1, S-3
(D) P-2, Q-3, R-4, S-1

2013

101. Which specific component of the nitrogenase enzyme complex contains the unique iron-molybdenum cofactor essential for fixing atmospheric dinitrogen?
(A) Dinitrogenase (MoFe protein)
(B) Dinitrogenase reductase
(C) Ferredoxin
(D) Leghemoglobin

2002

102. In plant epigenetics, which enzyme family is responsible for the maintenance of CG methylation during semi-conservative DNA replication?
(A) Histone deacetylases (HDACs)
(B) DNA methyltransferases (MET1)
(C) Chromomethylases (CMT3)
(D) Domains rearranged methyltransferases (DRM2)

2003

103. Which functional genomics technique is explicitly designed to measure the comprehensive expression levels of thousands of mRNA transcripts simultaneously?
(A) DNA footprinting
(B) RNA sequencing (RNA-seq)
(C) Western blotting
(D) Isoelectric focusing

2005

104. Which common sequencing artifact is predominantly associated with standard Illumina sequencing platforms?
(A) Substitution errors driven by optical phasing and pre-phasing issues
(B) Extremely high insertion/deletion errors in homopolymer runs
(C) Inability to sequence fragments shorter than 10 kilobases
(D) Total failure to sequence GC-rich regions

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(B) They serve as repressors that bind to and inhibit MYC transcription factors.
(C) They are specific ubiquitin ligases.
(D) They synthesize jasmonic acid in the chloroplast.

2025

64. In plant cells, mature miRNAs are incorporated into an effector complex. What is the standard biological acronym for this specific complex?
(A) SNF
(B) PEP
(C) HAT
(D) RISC

2019

65. Post-Transcriptional Gene Silencing (PTGS) is fundamentally triggered by the cellular presence of what anomalous nucleic acid structure?
(A) Single-stranded DNA loops
(B) Triple-helical DNA
(C) Circular non-coding RNAs
(D) Double-stranded RNA

2002

66. Restriction Fragment Length Polymorphisms (RFLPs) require the use of which enzymes to generate the variable DNA fragments analyzed?
(A) DNA ligases
(B) Restriction endonucleases
(C) Reverse transcriptases
(D) Taq polymerases

2024

67. The utilization of molecular markers to selectively introgress a specific trait into a recurrent background parent while rapidly recovering the recurrent genome is defined as:
(A) Mutagenesis breeding
(B) Marker-Assisted Backcrossing (MABC)
(C) Transgenic modification
(D) Clonal propagation

2024

68. The basic structural fiber of packed chromatin in eukaryotic nuclei often exhibits a diameter typically estimated at:
(A) 2 nm
(B) 10 nm
(C) 30 nm
(D) 300 nm

2008

69. Most repetitive genomic DNA is categorized as either tandemly arrayed or interspersed. Which of the following represents an interspersed repeat?
(A) Telomeric repeats
(B) Ribosomal DNA arrays
(C) Long interspersed nuclear elements (LINEs)
(D) Centromeric satellites

NODIA

2018

70. Arrange the following functional elements of a typical eukaryotic gene in the correct 5' to 3' physical order:
I. Promoter region
II. Start codon (ATG)
III. Polyadenylation signal
IV. 5' Untranslated Region (5' UTR)
(A) I, IV, II, III
(B) IV, I, II, III
(C) I, II, IV, III
(D) II, I, III, IV

2002

71. The phenomenon of multipartite mitochondrial genome structure is facilitated by the presence of large regions of identical sequence. What are these regions called?
(A) Centromeres
(B) Exons
(C) Repeat pairs
(D) Splice sites

2007

72. Which portion of a mature eukaryotic mRNA is added post-transcriptionally and is crucial for preventing exonuclease degradation at the 3' end?
(A) The poly(A) tail
(B) The 5' cap
(C) Intron lariats
(D) The Kozak sequence

2024

73. During nuclear transcription, which core promoter element provides the binding site for the TATA-binding protein (TBP)?
(A) Initiator (Inr)
(B) TATA box
(C) Enhancer element
(D) CCAAT box

2009

74. Which specialized DNA-binding motif is characterized by an alpha helix and a beta turn that securely docks into the major groove of DNA?
(A) Zinc finger
(B) Leucine zipper

through the egg cell.
(B) Nuclear genomes are entirely excluded from pollen.
(C) CMS is linked to the X chromosome.
(D) Chloroplasts actively destroy paternal mitochondria.

2005

116. A single nuclear gene sequence can potentially yield multiple distinct mature mRNA isoforms. Which process is primarily responsible for this diversity?
(A) Promotor hypermethylation
(B) Alternative splicing
(C) DNA double-strand break repair
(D) Retrograde signaling

2014

117. Eukaryotic RNA polymerase II is explicitly responsible for synthesizing which class of RNA molecules?
(A) Ribosomal RNA (rRNA)
(B) Transfer RNA (tRNA)
(C) Messenger RNA (mRNA)
(D) Small nucleolar RNA (snoRNA) exclusively

2008

118. Which structural motif is NOT typically recognized as a DNA-binding domain in plant transcription factors?
(A) Basic Leucine Zipper (bZIP)
(B) Myb-like domain
(C) WRKY domain
(D) Pleckstrin homology (PH) domain

2016

119. A seed-specific promoter often includes critical cis-regulatory sequence motifs known as:
(A) RY repeats
(B) HSE boxes
(C) DRE core elements
(D) GC boxes

2022

120. Consider the following statements about transcription in chloroplasts:
I. PEP is a multi-subunit enzyme encoded by the plastid genome.
II. NEP is a single-subunit enzyme encoded by the nuclear genome.
III. PEP recognizes promoters containing standard -10 and -35 bacterial-like elements.
IV. NEP exclusively transcribes structural genes of photosynthesis.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) II and III
(C) IV only
(D) I, II and III

2006

121. The fertility restorer (Rf) genes operate by mitigating the deleterious effects of CMS proteins. They typically achieve this by:
(A) Processing or degrading abnormal mitochondrial transcripts
(B) Suppressing the nuclear genome mutations
(C) Replacing the mitochondria with functional chloroplasts
(D) Activating a rapid hippocampal response in the anther

2025

122. The synthesis of the Rubisco holoenzyme requires precise stoichiometry. How does the cell ensure that sufficient large and small subunits are produced?
(A) Retrograde signaling from plastid to nuclear rbcS transcription
(B) Coupling their translation on a single polycistronic mRNA.
(C) Encoding both genes identically in both genomes.
(D) Synthesizing only the large subunit until darkness falls.

2022

123. The root nodule symbiosis is characterized by a unique oxygen-binding protein that prevents oxygen poisoning of nitrogenase. What is this protein?
(A) Phytohemagglutinin
(B) Leghemoglobin
(C) Plastocyanin
(D) Ferredoxin

2015

124. Chromatin remodeling complexes actively reposition nucleosomes to regulate gene expression. This specific process directly consumes energy derived from:
(A) ATP hydrolysis
(B) GTP hydrolysis
(C) NADH oxidation
(D) Cyclic AMP

2008

125. Which experimental technique confirms the functional identity of a newly cloned gene by knocking down its expression via homologous recombination?

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(D) Proteases

2002

86. Plant siRNAs are distinguished from plant miRNAs primarily by which biogenesis characteristic?
(A) siRNAs derive from dsRNA precursors; miRNAs derive from hairpins.
(B) siRNAs are exported to mitochondria; miRNAs remain in the nucleus.
(C) siRNAs are synthesized by DNA polymerase; miRNAs by RNA polymerase.
(D) siRNAs do not require Dicer enzymes for cellular processing.

2025

87. The successful assembly of the RNA-Induced Silencing Complex (RISC) strictly depends on the incorporation of which functional nucleic acid component?
(A) The complete double-stranded RNA molecule
(B) The passenger strand exclusively
(C) The guide strand
(D) The poly-A tail

2018

88. Amplified Fragment Length Polymorphism (AFLP) markers are highly reproducible because they combine the principles of which two fundamental molecular techniques?
(A) RFLP and Northern blotting
(B) Restriction digestion and PCR amplification
(C) Microarray hybridization and Sanger sequencing
(D) Southern blotting and ELISA

2008

89. Single Nucleotide Polymorphism (SNP) markers offer the highest genomic resolution for diversity analysis primarily because:
(A) They are completely dominant markers.
(B) They represent the most abundant source of sequence variation in genomes.
(C) They only occur in intergenic repetitive regions.
(D) They require large amounts of intact RNA.

2018

90. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : PacBio SMRT sequencing is often classified as a third-generation sequencing technology.
Reason (R) : It sequences single molecules in real-time without the requirement of pre-amplification by PCR.
Which of the above statement(s) is/are correct?
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

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2008

91. A key distinction between euchromatin and heterochromatin is that euchromatin generally exhibits which characteristic?
(A) It is transcriptionally active and less condensed.
(B) It is densely stained during interphase.
(C) It is exclusively located at centromeres.
(D) It lacks histone proteins entirely.

2015

92. The proliferation of class I transposable elements directly contributes to the C-value paradox by significantly expanding genome size. By what intermediate do these elements transpose?
(A) A DNA intermediate
(B) An RNA intermediate
(C) A protein intermediate
(D) A lipid intermediate

2024

93. If a spontaneous mutation deletes one of the large inverted repeats (IRs) in a chloroplast genome, what structural configuration is typically observed?
(A) The genome loses its characteristic four-part circular organization.
(B) The genome becomes segmented into multiple linear pieces.
(C) The chloroplast immediately converts into a mitochondrion.
(D) The plant adopts a purely parasitic lifestyle.

2012

94. Plant mitochondrial genomes exhibit remarkably slow rates of sequence evolution. However, they demonstrate high rates of which structural event?
(A) Exon skipping
(B) Point mutations
(C) Transposon excision
(D) Genomic rearrangement

(C) Beta barrel
(D) Helix-turn-helix

2023

75. Which reporter gene is most frequently fused to plant promoters to visually assay tissue-specific expression using histochemical staining?
(A) Antibiotic resistance (nptII)
(B) Glyphosate resistance (CP4 EPSPS)
(C) Acetolactate synthase (ALS)
(D) GUS (uidA)

2018

76. In chloroplasts, the expression of genes via the NEP system is primarily regulated by the nucleus, highlighting what type of signaling?
(A) Retrograde signaling
(B) Anterograde signaling
(C) Paracrine signaling
(D) Endocrine signaling

2013

77. The restorer of fertility (Rf) genes functionally restore pollen fertility in CMS lines predominantly by doing what?
(A) Modifying or degrading the toxic mitochondrial transcripts
(B) Suppressing the nuclear genome mutations
(C) Replacing the chloroplast genome entirely
(D) Inhibiting general translation in tapetal cells

2010

78. Which statement correctly identifies a unique genetic feature of the Rubisco enzyme complex?
(A) Both subunits are synthesized in the cytoplasm.
(B) Both subunits are strictly encoded by the plastome.
(C) It functions optimally without the binding of magnesium ions.
(D) It requires chaperonins for proper folding and assembly.

2016

79. In rhizobial nitrogen fixation, the expression of the nif genes is tightly repressed in the presence of high environmental concentrations of which element?
(A) Phosphorus
(B) Nitrogen
(C) Iron
(D) Calcium

2003

80. Cytosine methylation in plant genomes occurs in multiple sequence contexts. Which of the following is NOT a recognized DNA methylation context in plants?
(A) CG
(B) CHG
(C) CHH
(D) CAU

2015

81. Which strategy would a researcher employ to definitively validate the essential biological function of an uncharacterized gene discovered during structural genomics?
(A) Generating and analyzing a knockout mutant for the gene
(B) Sequencing the organism's entire genome again
(C) Measuring the centromere length of the chromosomes
(D) Purifying the organism's total lipid content

2001

82. Which next-generation sequencing technology relies directly on detecting the release of hydrogen ions (protons) during DNA synthesis?
(A) Ion Torrent
(B) Illumina MiSeq
(C) Oxford Nanopore
(D) PacBio Sequel

2007

83. The DREB (Dehydration Responsive Element Binding) transcription factors play a pivotal role in regulating plant responses to which specific stress combination?
(A) Drought and cold stress
(B) Pathogen and herbivore attack
(C) Heavy metal toxicity and shade avoidance
(D) Hypoxia and flooding

2025

84. Which plant hormone binds directly to the TIR1 receptor, initiating a cascade that leads to repressor degradation?
(A) Auxin
(B) Abscisic acid
(C) Cytokinin
(D) Ethylene

2022

85. ABA signaling relies on the PYR/PYL/RCAR receptors. Upon binding ABA, these receptors physically interact with and inhibit which specific class of enzymes?
(A) Kinases
(B) Phosphatases (PP2Cs)
(C) Ubiquitin ligases

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2013

105. Abiotic stress pathways frequently converge on the synthesis of protective chaperone proteins that prevent protein denaturation. Which family encapsulates these chaperones?
(A) Heat Shock Proteins (HSPs)
(B) Nucleases
(C) Ligases
(D) Polymerases

2010

106. In G-protein coupled signaling pathways, what specific biochemical action terminates the active signaling state of the G-alpha subunit?
(A) Exchange of GDP for GTP
(B) Hydrolysis of GTP to GDP
(C) Phosphorylation by a receptor kinase
(D) Ubiquitination and degradation

2014

107. The initial perception of the ethylene hormone signal occurs via specific receptors primarily localized to which cellular membrane?
(A) Plasma membrane
(B) Nuclear envelope
(C) Endoplasmic reticulum membrane
(D) Thylakoid membrane

2016

108. The specificity of microRNA-mediated gene silencing in plants relies upon near-perfect base pairing with which region of the target transcript?
(A) The 5' UTR exclusively
(B) The internal introns
(C) The target mRNA coding sequence
(D) The extreme 3' poly-A tail

2015

109. RNA interference is highly effective in functional validation experiments. Why might a researcher choose RNAi over creating a stable knockout line?
(A) RNAi physically deletes the gene from the genome permanently.
(B) RNAi allows viable knockdowns of genes that are otherwise lethal.
(C) RNAi requires no experimental delivery into the host cell.
(D) RNAi exclusively silences entire chromosomes simultaneously.

2001

110. Consider the following statements about Simple Sequence Repeats (SSRs):
I. They consist of tandemly repeated core motifs of 1-6 base pairs.
II. They are highly polymorphic due to slipped-strand mispairing during replication.
III. They are invariably dominant markers unable to distinguish heterozygotes.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2015

111. High-density genetic maps generated via SNP genotyping are essential prerequisites for which modern plant breeding methodology?
(A) Random chemical mutagenesis
(B) Genome-Wide Association Studies (GWAS)
(C) Protoplast fusion
(D) Meristem tissue culture

2011

112. The organization of plant chromatin is dynamically regulated. What specific chemical group is typically removed by HDAC enzymes to promote chromatin condensation?
(A) Methyl groups
(B) Acetyl groups
(C) Phosphate groups
(D) Hydroxyl groups

2022

113. Some plant genomes, such as those of the Liliaceae family, possess enormous amounts of DNA. This phenomenon primarily results from the massive accumulation of:
(A) Unique single-copy genes
(B) Retrotransposons
(C) Centromeric structural proteins
(D) Essential housekeeping genes

2025

114. The typical small single-copy (SSC) region in a chloroplast plastome most notably contains genes essential for:
(A) Nitrogen fixation
(B) Respiration
(C) Specific subunits of the NADH dehydrogenase complex
(D) Floral volatile biosynthesis

NODIA

2005

115. Cytoplasmic Male Sterility (CMS) is a maternally inherited trait. Why is the mutation responsible for CMS predictably inherited maternally in most crop species?
(A) Mitochondria are predominantly transmitted

2022

53. Which promoter strategy would be most suitable to ensure a transgene is only expressed during seed maturation?
(A) Using a phaseolin or oleosin promoter
(B) Using the Cauliflower Mosaic Virus 35S promoter
(C) Using a continuous ubiquitin promoter
(D) Using a minimal TATA box without enhancers

2005

54. The switch between Nuclear-Encoded Polymerase (NEP) and Plastid-Encoded Polymerase (PEP) usage in chloroplasts correlates strongly with which developmental transition?
(A) From mature chloroplast to senescent gerontoplast
(B) From proplastid to mature photosynthetic chloroplast
(C) From amyloplast to elaioplast
(D) From root nodule to mature root hair

2018

55. The Texas (T) cytoplasm in maize is a classic example of Cytoplasmic Male Sterility caused by a mitochondrial mutation. Which specific chimeric gene is responsible for T-CMS?
(A) orf107
(B) T-urf13
(C) orf239
(D) atp6

2012

56. What is the primary functional consequence of coordinating the expression of rbcS (nuclear) and rbcL (chloroplast) genes during active photosynthesis?
(A) Increasing the mutation rate of chloroplast DNA
(B) Inhibiting starch biosynthesis in the dark
(C) Degrading the thylakoid membrane
(D) Preventing the accumulation of unbound Rubisco small subunits

2019

57. In free-living diazotrophs and symbiotic rhizobia, the nitrogenase enzyme complex is profoundly sensitive to and irreversibly inactivated by which common molecule?
(A) Carbon dioxide
(B) Oxygen
(C) Hydrogen gas
(D) Nitrogen gas

2018

58. The SWI/SNF complex represents a class of epigenetic regulators specifically responsible for what cellular function?
(A) Adding methyl groups to DNA
(B) Cleaving targeted mRNA transcripts
(C) ATP-dependent chromatin remodeling
(D) Phosphorylating receptor kinases

2002

59. Transcriptomics generally provides a dynamic view of the cell by quantifying the abundance of which class of molecules?
(A) Intact genomic DNA fragments
(B) Mature folded proteins
(C) Cellular metabolites
(D) Total messenger RNAs

2012

60. Which of the following represents the correct sequence of fundamental steps in an Illumina sequencing workflow?
(A) Library preparation → Bridge amplification → Sequencing by synthesis → Data analysis
(B) Bridge amplification → Sequencing by synthesis → Library preparation → Data analysis
(C) Data analysis → Library preparation → Bridge amplification → Sequencing by synthesis
(D) Sequencing by synthesis → Bridge amplification → Library preparation → Data analysis

2015

61. Heat shock transcription factors (HSFs) trigger the expression of heat shock proteins primarily by binding to which specific cis-elements?
(A) DRE (Dehydration Responsive Elements)
(B) ABRE (ABA Responsive Elements)
(C) LTR (Low Temperature Responses)
(D) HSE (Heat Shock Elements)

2005

62. Secondary messengers are integral to plant signaling pathways. Which of the following is considered a major secondary messenger?
(A) Inositol 1,4,5-trisphosphate (IP3)
(B) RNA Polymerase
(C) Rubisco
(D) Proteasome subunit

2025

63. In the Jasmonate signaling pathway, what is the role of the JAZ family of proteins?
(A) They act as direct transcription activators.

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(A) Gene targeting/knockout
(B) Northern blot
(C) Agrobacterium floral dip
(D) Whole exome sequencing

2001

126. Oxford Nanopore technology uniquely differs from Illumina and PacBio by:
(A) Measuring current disruptions without DNA polymerase synthesis
(B) Utilizing fluorescent reversible terminators.
(C) Reading only short fragments of maximum 150 base pairs.
(D) Relying entirely on capillary electrophoresis.

2009

127. The SOS1 protein is a critical component of the Salt Overly Sensitive pathway. Functionally, SOS1 operates as a:
(A) Serine/threonine kinase
(B) Plasma membrane Na+/H+ antiporter
(C) Vacuolar proton pump
(D) Transcription factor

2006

128. Mitogen-Activated Protein Kinase (MAPK) cascades generally transmit extracellular stress signals into the nucleus through a strict sequential order. What is the standard configuration?
(A) MAPKKK → MAPKK → MAPK
(B) MAPK → MAPKK → MAPKKK
(C) MAPKK → MAPK → MAPKKK
(D) MAPKKK → MAPK → MAPKK

2012

129. Ubiquitination marks regulatory proteins for degradation by the 26S proteasome. Which component of the ubiquitination machinery explicitly determines the target specificity?
(A) E1 (Ubiquitin-activating enzyme)
(B) E2 (Ubiquitin-conjugating enzyme)
(C) E3 (Ubiquitin ligase)
(D) The 20S core particle

2018

130. Consider the following statements about plant endogenous small RNAs:
I. miRNAs regulate target genes generally by transcript cleavage.
II. siRNAs often regulate targets via DNA methylation.
III. DICER-LIKE (DCL) enzymes process their precursors.
IV. Their final effector complex always requires an Argonaute protein.
V. They are primarily responsible for synthesizing entirely new proteins.
Which of the above statement(s) is/are INCORRECT?
(A) I and III
(B) II, III and IV
(C) V only
(D) I, II and IV

2008

131. In the RNAi pathway, the strand of the short double-stranded RNA that is NOT loaded into the active RISC complex is termed the:
(A) Guide strand
(B) Passenger strand
(C) Silencing strand
(D) Catalytic strand

2025

132. Which molecular marker system strictly exploits the presence of single base substitutions and small indels in the genome?
(A) RFLP
(B) SSR
(C) SNP
(D) RAPD

2013

133. Marker-Assisted Selection (MAS) significantly accelerates the breeding cycle because it primarily evaluates selections based on:
(A) Genotypic profiling at early developmental stages
(B) Mature plant phenotypic manifestations
(C) The visual appearance of fully ripened fruit
(D) Complete genome sequencing of every individual plant

2014

134. Which biochemical structural element ensures that nucleosomes pack efficiently into the 30 nm fiber?
(A) The flexible N-terminal tails of the core histones
(B) The central non-coding RNA
(C) The lipid bilayer of the nuclear envelope
(D) Telomerase enzymes

2018

135. The vast majority of the maize genome consists of repetitive DNA. Which specific class of retrotransposons is overwhelmingly abundant in the maize genome?
(A) SINEs
(B) LTR (Long Terminal Repeat) retrotransposons
(C) P-elements

NODIA

molecular markers detect variations at the level of:
(A) Genomic DNA sequence
(B) Refined protein structure
(C) Expressed mRNA levels
(D) Cellular metabolic output

2024

216. Eukaryotic chromatin structurally organizes into defined territories within the interphase nucleus. Which statement best defines these territories?
(A) Chromosomes occupy distinct spatial domains
(B) They are unorganized random tangles of DNA.
(C) All chromosomes aggregate tightly into a single central mass.
(D) Only actively transcribed genes remain within the nucleus.

2002

217. The C-value refers to the amount of DNA in a haploid genome. Which plant highlights the C-value paradox by possessing a genome vastly larger than Arabidopsis despite similar biological complexity?
(A) Fritillaria assyriaca
(B) Oryza sativa (Rice)
(C) Solanum lycopersicum (Tomato)
(D) Zea mays (Maize)

2012

218. The chloroplast genome primarily utilizes a form of prokaryotic-like replication mechanism known as:
(A) Rolling circle amplification and D-loop replication
(B) Dispersive replication
(C) Reverse transcription integration
(D) Single-stranded gap repair

2008

219. Plant mitochondrial genomes often contain integrated segments of DNA logically derived from the chloroplast or nucleus. These segments are termed:
(A) Promiscuous DNA
(B) Plasmids
(C) Introns
(D) Telomeres

2018

220. Consider the following statements regarding the fine structure of eukaryotic genes:
I. Introns must be completely removed for correct protein synthesis.
II. The 5' UTR typically lacks any regulatory function.
III. The promoter strictly dictates the basal level of transcription.
IV. Enhancers can drastically increase the rate of transcription.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, III and IV
(C) II, III and IV
(D) I and III

2006

221. Which fundamental sequence modification defines the 5' cap of a mature eukaryotic mRNA transcript?
(A) A 7-methylguanosine via 5'-5' triphosphate bridge
(B) A methyl group added to the first adenine base
(C) A string of continuous uracil nucleotides
(D) An inverted repeat forming a stable stem-loop

2012

222. Trans-acting factors modulate gene expression. The fundamental defining characteristic of a "trans-acting" element compared to a "cis-acting" element is that it:
(A) Is a diffusible molecule encoded anywhere
(B) Must be physically located adjacent to its target gene.
(C) Is strictly a non-coding RNA sequence.
(D) Operates exclusively inside the nucleolus.

2018

223. Endosperm-specific promoters are desirable for biotechnological applications aimed at improving seed nutritional quality. Which well-known promoter drives strictly endosperm-specific expression?
(A) The Glutelin (Gt1) promoter
(B) The 35S Cauliflower Mosaic Virus promoter
(C) The Ubiquitin1 promoter
(D) The Actin1 promoter

2015

224. Chloroplast transcription requires dynamic interplay between nuclear and plastid mechanisms. The structural transition from proplastid to mature chloroplast is driven by:
(A) Sequential action of early NEP followed by late PEP
(B) The exclusive action of PEP
(C) The total elimination of all plastid DNA

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(B) Read mapping (Reference-based assembly)
(C) Annotation
(D) Functional validation

2014

145. Cold acclimation and freezing tolerance in Arabidopsis are principally coordinated by which family of transcription factors?
(A) CBF/DREB1
(B) MYC/MYB
(C) ARF
(D) HSF

2006

146. Which structural component of standard G-protein signaling acts directly as a primary molecular switch binding GTP?
(A) The G-alpha subunit
(B) The effector kinase
(C) The seven-transmembrane domain receptor
(D) The secondary messenger IP3

2009

147. GA (Gibberellic Acid) promotes stem elongation and seed germination. Upon GA binding to its receptor GID1, which class of repressor proteins is targeted for proteasomal degradation?
(A) DELLA
(B) JAZ
(C) AUX/IAA
(D) EIN3

2015

148. Which fundamental characteristic distinguishes plant miRNAs from siRNAs?
(A) miRNAs originate from single-stranded hairpin precursors
(B) miRNAs originate strictly from exogenous viral infections.
(C) miRNAs are completely incapable of binding to mRNA targets.
(D) miRNAs act exclusively in the mitochondria.

2023

149. The precise systemic spread of the RNAi silencing signal throughout a plant indicates that the mobile signal travels via which vascular tissue?
(A) Xylem
(B) Phloem
(C) Epidermis
(D) Pith

2024

150. Match the molecular marker type in List I with its defining functional characteristic in List II:
List I : (Marker Type)
P. RAPD
Q. RFLP
R. SSR
S. SNP
List II : (Characteristic)
1. Co-dominant length variation of tandem repeats
2. Single base pair variation
3. Dominant arbitrary primer amplification
4. Co-dominant restriction site variation
(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-2, Q-1, R-4, S-3
(D) P-1, Q-2, R-3, S-4

2003

151. Which factor strictly limits the successful application of Marker-Assisted Selection for complex quantitative traits?
(A) Control by many minor-effect genes (QTLs)
(B) The requirement of hazardous radioactive isotopes.
(C) Markers cannot be applied to seedling DNA.
(D) Molecular markers invariably alter the plant phenotype.

2009

152. In eukaryotic nuclear architecture, which structure physically connects the chromatin to the inner nuclear membrane and provides structural support?
(A) The nucleolus
(B) The nuclear lamina
(C) The spindle apparatus
(D) The nuclear pore complex

2004

153. A significant consequence of abundant LTR retrotransposon activity in plant genomes is:
(A) Proliferation of nested elements and genome expansion
(B) A severe reduction in total genome size
(C) The immediate destruction of all centromeres
(D) The complete suppression of homologous recombination

2012

154. The standard chloroplast genome features two single-copy regions separated by inverted repeats. These are specifically referred to as:
(A) Variable Region A and Variable Region B
(B) Exon 1 and Exon 2
(C) Short Single Copy (SSC) and Large Single Copy (LSC)
(D) Core Plasmids 1 and 2

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2012

175. While the core structural genes for photosynthesis are plastid-encoded, the vast majority of chloroplast functional proteins are encoded where?
(A) Within the nuclear genome
(B) Within the inverted repeat of the plastome
(C) Within the large single-copy region of the plastome
(D) Within the mitochondrial master circle

2012

176. Which unique feature allows RNA editing in plant mitochondria to alter the functional capability of mitochondrial gene transcripts?
(A) Codon modifications generating functional starts or stops
(B) It inserts long tracts of repetitive DNA into the mRNA.
(C) It causes widespread alternative splicing of the master circle.
(D) It methylates the RNA perfectly to prevent degradation.

2023

177. Regulatory sequences in a eukaryotic gene that drastically reduce the level of transcription when bound by repressor proteins are called:
(A) Enhancers
(B) Silencers
(C) Insulators
(D) Introns

2014

178. Eukaryotic transcripts undergo an essential process where non-coding introns are excised and exons are ligated. What is this molecular process strictly termed?
(A) Capping
(B) Polyadenylation
(C) Splicing
(D) Reverse transcription

2003

179. A tissue-specific promoter functionally relies upon unique trans-acting factors present only in the target tissue. What determines the exact interaction between the trans-factor and the promoter?
(A) Specific cis-regulatory nucleotide motifs in the promoter
(B) The physical length of the promoter sequence
(C) The distance of the promoter from the centromere
(D) The presence of a poly-A tail on the transcription factor

2011

180. Which category of RNA polymerase requires auxiliary sigma factors to selectively identify and bind to its cognate promoter sequences?
(A) Nuclear RNA Polymerase II
(B) Nuclear RNA Polymerase I
(C) Plastid-Encoded Polymerase (PEP)
(D) Nuclear-Encoded Polymerase (NEP)

2014

181. Restorer of fertility (Rf) genes counter the effects of Cytoplasmic Male Sterility (CMS). Physiologically, the expression of CMS predominantly triggers premature cellular death in which specific floral tissue?
(A) The tapetum layer of the anther
(B) The stigmatic papillae
(C) The ovule integuments
(D) The petal epidermis

2018

182. A genetic mutation that abolishes the function of the TIC translocon complex would have the most direct and catastrophic effect on the assembly of which enzyme?
(A) Rubisco holoenzyme
(B) Nitrogenase
(C) Mitochondrial ATP synthase
(D) RNA Polymerase II

2002

183. Nitrogen-fixing rhizobia utilize complex chemical signaling to recognize their appropriate legume hosts. The initial host-derived signal molecule is typically a:
(A) Flavonoid
(B) Gibberellin
(C) Volatile organic compound (VOC)
(D) Terpenoid

NODIA

2022

184. Chromatin remodeling often involves sliding nucleosomes along the DNA. This structural manipulation fundamentally alters the accessibility of:
(A) Promoter regions for transcription factor binding
(B) Intron splice sites
(C) Ribosomal binding sites on mRNA
(D) The terminal poly-A signal

2007

185. Forward genetics proceeds from a mutant phenotype to the identification of the causative gene. Conversely, reverse genetics fundamentally relies on:

(B) It chemically prevents the synthesis of secondary DNA structures.
(C) It massively amplifies the DNA sequence geometrically.
(D) It actively cleaves the DNA into standardized 100 bp fragments.

2018

166. Under intense heat stress, unfolded proteins rapidly accumulate in the cytoplasm. The induction of Heat Shock Proteins (HSPs) primarily serves to:
(A) Assist in the correct refolding of denatured proteins
(B) Act as transcriptional repressors to shut down all cellular activity
(C) Increase the kinetic rate of all metabolic enzymes indiscriminately
(D) Disrupt the plasma membrane to release heat

2017

167. Phytohormone receptors exhibit varied subcellular localizations. The well-characterized Auxin receptor, TIR1, predominantly functions within which cellular compartment?
(A) The cell wall matrix
(B) The plasma membrane surface
(C) The nucleus
(D) The thylakoid lumen

2002

168. The targeted degradation of regulatory proteins in hormone signaling requires their tagging with multiple ubiquitin molecules. This polyubiquitin chain is specifically recognized by the:
(A) Lysosome
(B) 26S proteasome
(C) Spliceosome
(D) Ribosome

2021

169. Plant endogenous small interfering RNAs (siRNAs) frequently participate in RNA-directed DNA Methylation (RdDM). What is the ultimate functional outcome of RdDM?
(A) Post-transcriptional mRNA cleavage
(B) Transcriptional gene silencing via chromatin modifications
(C) Enhancing translational elongation rates
(D) Promoting random homologous recombination

2015

170. Arrange the progressive structural levels of chromatin organization in eukaryotes from the simplest to the most highly condensed:
I. 30-nm chromatin fiber
II. Naked double-stranded DNA helix
III. Metaphase chromosome
IV. Nucleosome core particle ("beads on a string")
(A) II, IV, I, III
(B) II, I, IV, III
(C) IV, II, I, III
(D) II, IV, III, I

2010

171. Simple Sequence Repeat (SSR) markers are extensively used because they are multiallelic and highly reproducible. They are assayed experimentally primarily using:
(A) Polymerase Chain Reaction (PCR) and fragment analysis
(B) Southern Blotting
(C) Microarrays
(D) Mass Spectrometry

2025

172. The ultimate success of Marker-Assisted Backcrossing (MABC) relies on selecting for two sets of markers. Background selection specifically targets:
(A) The trait of interest from the donor parent
(B) Exclusively ribosomal RNA genes
(C) Only the mitochondrial DNA
(D) Recovery of the recurrent parent genome

2016

173. Transposons structurally alter genomic architecture. Which specific sequence hallmark reliably flanks a newly integrated DNA transposon?
(A) Target site duplications (TSDs)
(B) Poly-A tails
(C) Centromeric repeats
(D) Promotor sequences

2011

174. Which major category of transposable elements utilizes a reverse transcriptase enzyme as a necessary requirement for its transposition cycle?
(A) Class I Retrotransposons
(B) Class II DNA Transposons
(C) Miniature Inverted-repeat Transposable Elements (MITEs)
(D) Insertion Sequences (IS elements)

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2022

155. RNA editing in plant mitochondria often introduces functional start codons into transcripts. Which RNA editing event predominantly accomplishes this?
(A) C-to-U editing creating an AUG codon
(B) A-to-I editing creating an AUG codon
(C) U-to-C editing creating a GUG codon
(D) Deletion of a stop codon

2006

156. The highly conserved GT-AG rule applies specifically to which biological process?
(A) Transcription termination
(B) Polyadenylation site selection
(C) Splicing of eukaryotic pre-mRNA introns
(D) Translation initiation positioning

2021

157. Which sequence feature within a mature mRNA transcript defines the exact start site for ribosomal translation in eukaryotes?
(A) The Kozak consensus sequence enclosing an AUG start codon
(B) A continuous tract of poly-A nucleotides
(C) The TATA box binding site
(D) The highly structured 3' UTR hairpin

2005

158. Enhancers can loop over long physical distances to interact with the core promoter. This looping is structurally stabilized by which critical protein complex?
(A) Rubisco
(B) Dicer
(C) The Mediator complex
(D) Phototropin

2019

159. When selecting a promoter to drive strong, continuous, non-specific expression of a transgene in dicot plants, which promoter is most classically preferred?
(A) CaMV 35S
(B) RuBP carboxylase small subunit promoter
(C) Adh1 promoter
(D) Glutelin promoter

2025

160. Which of the following represents the correct sequence of action in the plant jasmonate signaling pathway?
(A) COI1 binding → JAZ degradation → MYC2 activation → Target gene expression
(B) MYC2 activation → COI1 binding → Target gene expression → JAZ degradation
(C) Target gene expression → JAZ degradation → MYC2 activation → COI1 binding
(D) JAZ degradation → COI1 binding → Target gene expression → MYC2 activation

2002

161. The structural assembly of the nuclear-encoded subunits of the Rubisco enzyme requires post-translational transit into the chloroplast. This transit typically relies on:
(A) Non-specific passive diffusion through porins
(B) The TIC and TOC translocon complexes
(C) Vesicle-mediated endocytosis
(D) Viral reverse transcriptase

2015

162. Biological nitrogen fixation heavily relies on maintaining an extremely low oxygen tension. Leghemoglobin functionally achieves this by:
(A) Catalyzing the reduction of nitrogen to ammonia
(B) Reversibly binding and buffering free oxygen in the nodule
(C) Actively pumping oxygen out of the plant roots
(D) Degrading completely into water and hydrogen

2024

163. DNA methylation in plants strongly correlates with transcriptional silencing. Which nuclear process strictly requires demethylation mechanisms to reset expression patterns?
(A) Respiration
(B) Gametogenesis and early embryogenesis
(C) Photosynthesis in mature leaves
(D) Basic cell wall synthesis

NODIA

2001

164. In the context of functional genomics, an RNA-seq experiment analyzes the transcriptome. What represents the most fundamental initial step in sample processing for RNA-seq?
(A) Total RNA extraction followed by mRNA enrichment
(B) Total DNA extraction and sonication
(C) Denaturing protein extraction
(D) Formaldehyde cross-linking of histones

2025

165. PacBio sequencing utilizes an immobilised DNA polymerase within a Zero-Mode Waveguide (ZMW). What specific advantage does the ZMW provide?
(A) It allows visualization of single fluorescent nucleotide events

(A) Starting with a known gene sequence to deduce function
(B) Sequencing only RNA instead of DNA
(C) Breeding highly phenotypically diverse populations
(D) Using purely classical Mendelian crosses

2002

186. The concept of "sequencing depth" or "coverage" in high-throughput sequencing refers to:
(A) The average representation of a base in the raw dataset
(B) The total physical length of the reads generated
(C) The distance between the sequencing instrument and the computer
(D) The physical size of the DNA fragments loaded into the machine

2019

187. The Salt Overly Sensitive (SOS) pathway represents a highly specific ion homeostasis network. The activation of the primary SOS3 sensor relies strictly on the binding of which ion?
(A) Calcium
(B) Potassium
(C) Chloride
(D) Magnesium

2023

188. Receptors embedded in the plasma membrane often utilize secondary messengers to relay signals intracellularly. Which of the following is NOT a typical secondary messenger?
(A) Heterotrimeric G-protein
(B) Calcium ions (Ca^{2+})
(C) Cyclic AMP (cAMP)
(D) Inositol 1,4,5-trisphosphate (IP3)

2011

189. Abscisic Acid (ABA) regulates the closure of stomata under water deficit conditions. ABA-induced stomatal closure relies on the efflux of which osmotically active ion from the guard cells?
(A) Potassium
(B) Sodium
(C) Calcium
(D) Hydrogen

2025

190. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : MicroRNAs (miRNAs) usually direct perfect or near-perfect cleavage of their target mRNAs in plants.
Reason (R) : Plant miRNAs strictly assemble with an Argonaute-containing RISC complex that possesses slicing endonuclease activity.
Which of the above statement(s) is/are correct?
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2012

191. Dicer-Like (DCL) enzymes require which structural feature in their RNA substrate to process it into functional small RNAs?
(A) A double-stranded RNA region
(B) A highly structured triple helix
(C) A perfectly single-stranded linear sequence
(D) A heavily methylated RNA sequence

2003

192. Amplified Fragment Length Polymorphism (AFLP) is a highly reliable marker technique. A significant inherent limitation of standard AFLP is that it typically acts as a:
(A) Dominant marker
(B) Co-dominant marker
(C) Recessive phenotypic marker
(D) Sex-linked marker

2016

193. Single Nucleotide Polymorphisms (SNPs) are robustly utilized in genome-wide association studies (GWAS) due primarily to their:
(A) High abundance and uniform genomic distribution
(B) Extremely large physical size
(C) Ability to independently repair DNA mutations
(D) Absolute lack of sequence variation

2014

194. Which class of repetitive elements is commonly clustered in massive tandem arrays at the physical ends of linear eukaryotic chromosomes?
(A) Telomeric repeats
(B) Centromeric satellites
(C) LTR retrotransposons
(D) Transposase genes

2001

195. Miniature Inverted-repeat Transposable Elements (MITEs) are abundant in plant genomes. They are structurally classified as:
(A) Non-autonomous DNA transposons

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(B) Autonomous retrotransposons
(C) Complete viral genomes
(D) Tandem multigene families

2004

196. The two identical inverted repeats in the chloroplast genome ensure that the genes contained within them exist in how many copies per circular plastome?
(A) Two
(B) One
(C) Three
(D) Four

2022

197. While plant mitochondrial genomes are multipartite and complex, they fundamentally encode proteins primarily required for which critical cellular process?
(A) Oxidative phosphorylation
(B) Glycolysis
(C) Photosynthetic light reactions
(D) Photorespiration

2006

198. The 3' untranslated region (3' UTR) of a eukaryotic mRNA plays a critical role in controlling what aspect of the transcript?
(A) Transcript stability and subcellular localization
(B) Initial clearance of the core promoter complex
(C) Rate of transcriptional elongation
(D) Efficient splicing of the first internal intron

2010

199. Polyadenylation functionally requires an endonuclease to cleave the nascent pre-mRNA immediately downstream of the consensus sequence. This cleavage is closely coupled with what event?
(A) Addition of a multi-adenine tract by poly-A polymerase
(B) Degradation of the entire RNA molecule
(C) The splicing of the final exon
(D) The insertion of a 5' cap

2014

200. Match the essential transcription component in List I with its core function in List II:
List I : (Component)
P. TATA-binding protein (TBP)
Q. Trans-acting activator
R. Enhancer
S. Spliceosome
List II : (Function)
1. Removes introns from pre-mRNA
2. Recognizes core promoter to recruit polymerase
3. Binds distal elements to upregulate expression
4. Distal cis-regulatory DNA sequence
(A) P-2, Q-3, R-4, S-1
(B) P-3, Q-2, R-1, S-4
(C) P-4, Q-1, R-3, S-2
(D) P-1, Q-4, R-2, S-3

2021

201. Tissue-specific expression constructs are valuable for crop improvement. Driving an insecticidal crystal protein gene with a leaf-specific promoter primarily avoids:
(A) Toxicity to non-target soil organisms exposed to roots
(B) Any potential insect resistance developing
(C) The need for chloroplast transformation
(D) Transcription occurring in daylight

2023

202. The Nuclear-Encoded Polymerase (NEP) is targeted to the chloroplast to transcribe genes critical during which specific stage?
(A) Early plastid development (proplastid stage)
(B) Senescence
(C) Maximum photosynthetic activity
(D) Dark-induced dormancy

NODIA

2010

203. Some Rf (restorer of fertility) genes act post-transcriptionally to neutralize CMS. They frequently encode Pentatricopeptide Repeat (PPR) proteins that directly target:
(A) Mitochondrial RNA editing or cleavage
(B) Nuclear promoter sequences
(C) Ribosomal RNA stability
(D) Chloroplast DNA replication

2006

204. Which structural component of Rubisco uniquely acts as the catalytic core where carbon dioxide is fixed to ribulose-1,5-bisphosphate?
(A) The large subunit encoded by the plastome
(B) The small subunit encoded by the nucleus
(C) The transit peptide
(D) The ferredoxin carrier

2011

205. The nifHDK genes encode the protein structural components of nitrogenase. The expression of these genes is regulated in response to oxygen levels by which specific two-component regulatory system?

(A) FixL / FixJ
(B) SOS2 / SOS3
(C) VirA / VirG
(D) NodD / Nod factor

2003

206. Histone methylation can correlate with either transcriptional activation or repression. Generally, methylation of which specific histone residue is a universal mark of active euchromatin?
(A) H3K4
(B) H3K9
(C) H3K27
(D) H4K20

2011

207. Creating a deletion of an endogenous gene to observe the resulting mutant phenotype is an example of:
(A) Functional genomics via targeted knockout
(B) Structural genomics via chromosome mapping
(C) Epigenomic profiling
(D) Transcriptomics

2017

208. Oxford Nanopore sequencing offers an advantage in resolving complex repetitive regions. Which technological characteristic specifically provides this advantage?
(A) Capacity to generate ultra-long continuous reads
(B) Its reliance on incredibly short 50-bp reads
(C) Its requirement for highly specific restriction enzymes
(D) Its massive reliance on PCR amplification

2024

209. Drought tolerance responses are mediated by Late Embryogenesis Abundant (LEA) proteins. Functionally, LEA proteins are highly hydrophilic and act as:
(A) Molecular shields protecting structures from desiccation
(B) Proteases to destroy damaged tissues
(C) Sequence-specific DNA transcription factors
(D) Transmembrane water channel aquaporins

2001

210. Consider the following statements about plant signaling kinase cascades:
I. They involve sequential phosphorylation to transmit signals.
II. A typical MAPK cascade requires only a single kinase enzyme.
III. They serve to amplify weak extracellular signals into strong intracellular responses.
Which of the above statement(s) is/are correct?
(A) I and II
(B) II and III
(C) I and III
(D) I only

2013

211. The mechanism of hormone signaling via repressor degradation links hormone perception directly to:
(A) Precise control of targeted protein destruction
(B) The immediate physical closure of stomata
(C) The synthesis of completely novel DNA
(D) The export of mitochondrial ATP

2004

212. Which statement accurately defines the regulatory targeting mechanism of plant microRNAs (miRNAs)?
(A) Slicing mRNA through AGO1-mediated guidance
(B) Binding DNA in promoters to induce methylation.
(C) They actively transport specific mRNAs out of the nucleus.
(D) They assemble functional ribosomes to promote translation.

2017

213. Virus-Induced Gene Silencing (VIGS) relies on harnessing the plant's endogenous RNAi machinery. What type of nucleic acid triggers the VIGS response?
(A) Double-stranded RNA viral intermediates
(B) Single-stranded plant DNA
(C) Polyadenylated host mRNA
(D) Circular host plasmids

2012

214. Which type of genetic marker system depends on identifying variations in the length of tandemly repeated core sequence blocks?
(A) Simple Sequence Repeats (SSRs)
(B) Restriction Fragment Length Polymorphisms (RFLPs)
(C) Single Nucleotide Polymorphisms (SNPs)
(D) Sequence Characterized Amplified Regions (SCARs)

2001

215. The core advantage of Marker-Assisted Selection (MAS) is its ability to bypass environmental influence on traits. This is possible because

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(D) Miniature Inverted-repeat Transposable Elements (MITEs)

2014

136. The phenomenon of RNA editing in plant mitochondria alters the encoded amino acid sequence. It provides functional correction primarily to transcripts of genes involved in:
(A) Starch synthesis
(B) Pigment synthesis
(C) Oxidative phosphorylation
(D) Photosystem II assembly

2005

137. Which statement correctly identifies a key functional difference between typical eukaryotic and prokaryotic mRNA?
(A) Prokaryotic mRNAs are frequently polycistronic; eukaryotic are monocistronic.
(B) Eukaryotic mRNAs always lack a poly(A) tail.
(C) Prokaryotic mRNAs are extensively spliced before translation.
(D) Eukaryotic mRNAs are translated simultaneously with transcription in the nucleus.

2014

138. Enhancers possess a unique feature distinguishing them from core promoters. Which characteristic is definitive of an enhancer element?
(A) It dictates the exact nucleotide where transcription initiates.
(B) It functions reliably regardless of upstream or downstream orientation.
(C) It provides the direct binding site for RNA polymerase II.
(D) It is immediately removed during mRNA splicing.

2017

139. Which genetic construct provides the most definitive experimental proof that a selected DNA sequence functions as a tissue-specific promoter?
(A) Transforming a plant with the promoter fused to a reporter gene
(B) Deleting the entire chromosome containing the promoter.
(C) Sequencing the promoter using Sanger technology.
(D) Digesting the promoter with a restriction enzyme.

2024

140. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : Plant mitochondria possess a complex multipartite genome structure rather than a single master circle.
Reason (R) : High-frequency homologous recombination mediated by large repeats continually breaks and rejoins the master circle into smaller subgenomic molecules.
Which of the above statement(s) is/are correct?
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2023

141. The coordinate expression of photosynthesis genes requires the import of numerous nuclear-encoded proteins into the chloroplast. This targeted import is mediated by which specialized sequence?
(A) A nuclear localization signal
(B) An N-terminal transit peptide
(C) A C-terminal poly-A tail
(D) An internal ribosome entry site

2011

142. In biological nitrogen fixation, the rhizobia physically enter the legume root cortex via a unique plant-derived structural adaptation called an:
(A) Appressorium
(B) Infection thread
(C) Haustorium
(D) Endodermis

2024

143. Which technique accurately determines specific genome-wide binding sites of a particular transcription factor in vivo?
(A) Chromatin Immunoprecipitation followed by sequencing (ChIP-seq)
(B) Northern Blotting
(C) Whole Genome Shotgun Sequencing
(D) Two-dimensional gel electrophoresis

NODIA

2024

144. High-Throughput Sequencing generates millions of short reads. The process of computationally aligning these reads to an existing completed genome sequence is defined as:
(A) De novo assembly

(D) Exogenous sugar import shutting down all transcription

2025

225. Cytoplasmic Male Sterility relies upon mitochondrial mutations affecting pollen development. These CMS-associated genes are typically classified as:
(A) Chimeric, novel open reading frames
(B) Completely normal essential respiratory genes
(C) Deleted chloroplast photosynthetic genes
(D) Overexpressed nuclear transcription factors

2008

226. The coordinated assembly of Rubisco requires chaperonins. The essential function of the Rubisco-specific chaperonin complex within the chloroplast is to:
(A) Prevent aggregation and facilitate correct folding
(B) Transcribe the rbcL gene
(C) Degrade any excess small subunits
(D) Transport the fully assembled enzyme out of the chloroplast

2019

227. Nitrogenase activity requires massive energetic input. The required ATP for symbiotic nitrogen fixation in root nodules is supplied by:
(A) Host plant-derived photosynthates
(B) The bacterial photosynthesis machinery
(C) Direct light absorption by the nodule tissue
(D) Fermentation of atmospheric nitrogen

2014

228. DNA methylation alters the physical structure of chromatin. It generally recruits which class of specialized proteins to enforce gene silencing?
(A) Methyl-CpG-binding domain (MBD) proteins
(B) Histone acetyltransferases (HATs)
(C) RNA polymerases
(D) Ribosomal subunits

2001

229. T-DNA insertional mutagenesis provides tools for functional genomics. The purpose of analyzing a T-DNA knockout line is to:
(A) Determine consequences of disabling a specific gene
(B) Increase the overall expression level of the target gene
(C) Synthesize novel artificial proteins
(D) Sequence the complete plant genome

2017

230. Consider the following statements about Illumina sequencing chemistry:
I. It relies on sequencing by synthesis.
II. It generates incredibly long reads exceeding 10,000 bases.
III. It utilizes fluorescently labeled reversible terminators.
IV. It requires bridge amplification to create clonal clusters.
V. It reads current changes directly across a protein pore.
Which of the above statement(s) is/are correct?
(A) I, III and IV
(B) I, II and V
(C) II, III and V
(D) I, IV and V

NODIA

2018

231. The primary function of the DREB1/CBF transcription factors during cold stress acclimation relies on:
(A) Binding DRE/CRT elements to upregulate COR genes
(B) Directly degrading frozen tissue structures
(C) Excreting large volumes of intracellular water
(D) Halting all translation across the entire cell

2018

232. G-protein-coupled receptors initiate downstream signaling through a structural change that promotes:
(A) Exchange of GDP for GTP on the G-alpha subunit
(B) The immediate cleavage of the target mRNA
(C) The continuous autophosphorylation of serine residues
(D) The immediate destruction of the entire receptor complex

2022

233. The gibberellin (GA) signaling pathway relies on the degradation of DELLA proteins. DELLA proteins functionally operate primarily as:
(A) Negative repressors of growth-promoting genes
(B) Essential core structural components of the ribosome
(C) Specialized hormone transport channels
(D) Light-harvesting accessory pigments

2016

234. Endogenous plant microRNAs fine-tune plant development. A mature functional miRNA

9. (D) Bacterial sigma-70 type promoters
The plastid-encoded polymerase in chloroplasts is a multi-subunit enzyme that shares structural and functional homology with bacterial RNA polymerases. It specifically recognizes promoter sequences that closely resemble the -10 and -35 consensus elements found in bacterial sigma-70 type promoters. This similarity reflects the endosymbiotic origin of chloroplasts and allows for the efficient transcription of genes essential for photosynthetic machinery.

10. (C) II and III
Cytoplasmic male sterility is a maternally inherited trait often associated with the presence of chimeric open reading frames in the mitochondrial genome. These novel genes interfere with pollen development, leading to male sterility. Nuclear restorer genes can suppress this phenotype by modifying or degrading the toxic mitochondrial transcripts. This system is widely utilized in hybrid seed production for various crop species.

11. (B) Chloroplast genome
The ribulose-1,5-bisphosphate carboxylase/oxygenase enzyme is composed of eight large and eight small subunits. The large subunit is encoded by the rbcL gene located within the chloroplast genome and synthesized on plastid ribosomes. In contrast, the small subunit is encoded by nuclear genes. Proper assembly of the functional holoenzyme requires tight coordination between the nuclear and plastid genetic compartments.

12. (C) nif genes
Biological nitrogen fixation is mediated by the nitrogenase enzyme complex, which is encoded by a cluster of nitrogen fixation genes. These nif genes code for structural components, such as dinitrogenase and dinitrogenase reductase, as well as enzymes involved in cofactor biosynthesis. This gene cluster is found in various diazotrophic bacteria, including both free-living species and those involved in symbiotic relationships.

13. (D) DNA methylation at specific cytosine residues
DNA methylation is a fundamental epigenetic modification involving the addition of a methyl group to cytosine residues, often in the CG, CHG, or CHH contexts. In plants, high levels of DNA methylation at promoter regions are strongly associated with transcriptional silencing and the formation of heterochromatin. This process plays a vital role in regulating gene expression and maintaining overall genomic stability.

14. (D) Generating transcriptomic profiles using microarrays
Functional genomics aims to understand the biological roles and interactions of genes on a global scale. Techniques like generating transcriptomic profiles using microarrays or RNA sequencing measure the dynamic expression of thousands of genes simultaneously. This differs from structural genomics, which focuses on the physical mapping and sequencing of the genome to determine its organization, composition, and the location of loci.

15. (A) Sequencing by synthesis with reversible terminators
Illumina high-throughput sequencing technology utilizes the principle of sequencing by synthesis on a solid surface. This process involves the incorporation of fluorescently labeled reversible terminators into a growing DNA strand. After each nucleotide addition, the fluorescence is detected and the terminator is chemically removed to allow the next base to be added. This method enables the simultaneous sequencing of millions of fragments.

16. (C) Sodium
Salt Overly Sensitive signaling is essential for maintaining ion homeostasis in plants exposed to high salinity. This pathway specifically regulates cellular levels of sodium ions to prevent toxicity. It involves a sensory mechanism that triggers a kinase cascade, ultimately activating transporters that export sodium from the cytoplasm. Proper functioning of this system is vital for plant survival under saline conditions.

17. (A) To amplify the signal via successive phosphorylation events
Kinase cascades are central to plant signal transduction, allowing cells to respond rapidly to environmental stimuli. These pathways function by transferring phosphate groups from one protein to the next in a sequential manner. This process serves to amplify the initial signal, ensuring that a small extracellular trigger results in a robust intracellular response, such as changes in gene transcription.

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(B) DNA polymerases
(C) Proteolytic degradation enzymes
(D) Transfer RNAs (tRNAs)

2007

244. Tissue-specific gene expression is driven by distinct combinatorial arrays of transcription factors. These factors recognize and bind to which specific structural element?
(A) Cis-regulatory elements in enhancers or promoters
(B) Universal TATA boxes
(C) The 3' poly-A tail
(D) The entirely translated coding sequence

2007

245. Driving a transgene with a constitutive promoter ensures that the gene is transcribed:
(A) Across virtually all tissues and developmental stages
(B) Only in senescing leaves
(C) Strictly in response to pathogen infection
(D) Only within the dark

2001

246. The Plastid-Encoded Polymerase (PEP) is a multisubunit enzyme structurally and functionally homologous to which polymerase?
(A) E. coli bacterial RNA Polymerase
(B) Eukaryotic RNA Polymerase II
(C) Retroviral Reverse Transcriptase
(D) Yeast mitochondrial polymerase

2014

247. The genetic restoration of fertility (Rf) in CMS systems demonstrates cross-talk between which two genomes?
(A) Nucleus and Mitochondria
(B) Chloroplast and Mitochondria
(C) Nucleus and Chloroplast
(D) Chloroplast and Vacuole

2018

248. The synthesis of Rubisco requires coordination. While the large subunit (rbcL) is transcribed within the chloroplast, the small subunit (rbcS) transcript resides where?
(A) In the nuclear genome
(B) In the nucleolus
(C) On the mitochondrial master circle
(D) Integrated within a retrotransposon

2025

249. The process of symbiotic nitrogen fixation restricts oxygen access to protect nitrogenase. Leghemoglobin acts as a buffer in which precise location?
(A) In the plant cytoplasm of infected nodule cells
(B) Inside the bacterial nucleoid
(C) Covering the external root surface
(D) Inside the xylem vessels

2023

250. Match the epigenetic regulatory mechanism in List I with its fundamental functional outcome in List II:
List I : (Mechanism)
P. DNA hypermethylation at promoters
Q. Histone H3K4 trimethylation
R. Histone deacetylation
S. Chromatin remodeling (SWI/SNF)
List II : (Outcome)
1. ATP-dependent repositioning of nucleosomes
2. Mark of highly active euchromatin
3. Generally promotes tight chromatin condensation
4. Strongly represses transcription initiation
(A) P-4, Q-2, R-3, S-1
(B) P-1, Q-4, R-2, S-3
(C) P-3, Q-1, R-4, S-2
(D) P-2, Q-3, R-1, S-4

NODIA

2006

251. Utilizing transcriptomics allows a researcher to survey:
(A) Dynamic expression levels of mRNA transcripts
(B) The fixed sequence of the entire genomic DNA
(C) The folded structures of all cellular proteins
(D) Only non-coding repetitive DNA sequences

2023

252. The Oxford Nanopore platform features a higher error rate compared to standard Illumina sequencing. What specific type of error dominates Nanopore read profiles?
(A) Indel errors around homopolymeric stretches
(B) Large-scale structural inversions
(C) Total failure to sequence purine bases
(D) Instantaneous fragmentation of DNA

2014

253. The SOS (Salt Overly Sensitive) pathway features a hierarchical kinase cascade. The final target of the activated SOS2 kinase is:
(A) SOS1 plasma membrane Na+/H+ antiporter
(B) DREB transcription factor
(C) Vacuolar ATPase

is generally characterized by an approximate sequence length of:
(A) 10-15 nucleotides
(B) 20-24 nucleotides
(C) 100-150 nucleotides
(D) Over 500 nucleotides

2019

235. The structural distinction between short interfering RNAs (siRNAs) and microRNAs (miRNAs) relies upon:
(A) miRNA derivation from hairpin structures
(B) The exact organelle where they function exclusively
(C) Their reversed direction of biological transcription
(D) Their inability to bind to any messenger RNA

2012

236. The Polymerase Chain Reaction (PCR) requires specific thermal cycling profiles. Which technique relies upon random, low-stringency PCR amplification to generate marker profiles?
(A) RAPD
(B) SSR
(C) RFLP
(D) SNP arrays

2003

237. Marker-Assisted Selection (MAS) provides advantages over conventional phenotypic selection when addressing traits that are:
(A) Scored with difficulty due to environmental variation
(B) Easily visually identified at the seedling stage
(C) Strictly controlled by a single perfectly dominant gene.
(D) Entirely unrelated to the plant's economic value

2013

238. Histone tails are subject to post-translational modifications. Which combination of modifications is generally regarded as the hallmark of silenced heterochromatin?
(A) Hypoacetylation and H3K9 methylation
(B) Hyperacetylation and H3K4 methylation
(C) Massive phosphorylation and ubiquitination
(D) Complete removal of all histone tails

2006

239. The massive variation in genome size observed across different angiosperm families (the C-value paradox) is predominantly explained by expansions in the copy number of:
(A) LTR Retrotransposons
(B) Core housekeeping genes
(C) Ribosomal RNA sequences
(D) Plastid DNA fragments integrated into the nucleus

2003

240. Given below are two statements: one is labelled as Assertion (A) and the other is labelled as Reason (R).
Assertion (A) : The chloroplast genome generally maintains stable structural configurations compared to the mitochondrial genome.
Reason (R) : The presence of two large inverted repeats separated by single-copy regions stabilizes the circular structural integrity of the plastome.
Which of the above statement(s) is/are correct?
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

241. Plant mitochondrial genomes undergo frequent homologous recombination. The physical consequence of this recombination across large repeated sequences is the generation of:
(A) A population of subgenomic structural circles
(B) Massive linear single-stranded DNA concatemers
(C) Complete duplication of the entire master circle
(D) Immediate destruction of the entire mitochondrial genome

2003

242. Eukaryotic core promoters dictate the precise location where transcription initiates. The TATA box typically resides how far upstream of the transcription start site?
(A) Between -25 and -30 base pairs
(B) Between -10 and -15 base pairs
(C) Exactly at +1
(D) Approximately at -250 base pairs

2016

243. Pre-mRNA splicing relies on a ribonucleoprotein complex called the spliceosome. The catalytic core of the spliceosome consists of:
(A) Small nuclear RNAs (snRNAs)

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2016

265. Nuclear transcription requires mRNA processing coupled to the polymerase. The 5' cap structure provides what distinct functional advantage?
(A) Protecting nascent transcripts from exonuclease degradation
(B) Accelerating intron excision
(C) Dictating the exact transcription termination point
(D) Blocking any subsequent translation

2016

266. Enhancer sequences govern upregulations in gene expression. The defining unique property of an enhancer is its:
(A) Insensitivity to orientation and distance relative to the promoter
(B) Demand to be physically adjacent to the start codon
(C) Ability to permanently alter the DNA sequence
(D) Requirement to remain unmethylated

2011

267. Using a powerful constitutive promoter is inappropriate if the intended biotechnological goal is to:
(A) Express a toxic insecticidal protein exclusively in roots
(B) Express a neutral reporter everywhere
(C) Express an essential housekeeping gene
(D) Continuously overproduce harmless GFP

2012

268. The developmental transition controlling chloroplast biogenesis relies on transitioning from:
(A) Early NEP transcription to dominant PEP transcription
(B) PEP transcription to exclusive NEP transcription
(C) Scattered transcription to zero shutdown
(D) Viral reverse transcription

2018

269. Restoring pollen fertility in a CMS line requires:
(A) Introducing the corresponding functional nuclear restorer (Rf) allele
(B) Removing every functional mitochondrion
(C) Mutating every identical nuclear gene
(D) Deliberately removing the entire chloroplast genome

2023

270. Efficient assembly of the Rubisco holoenzyme requires:
(A) Molecular chaperonins acting in the chloroplast stroma
(B) Nuclear synthesis of both large and small subunits
(C) Mitochondrial assembly of the primary core
(D) Extracellular secretion of the mature complex

2006

271. Symbiotic biological nitrogen fixation depends on the activity of the nitrogenase enzyme complex, which is characterized by its:
(A) Extreme sensitivity to irreversible inactivation by oxygen
(B) Ability to function only at temperatures exceeding 100 degrees Celsius
(C) Lack of metal cofactors
(D) Reliance on purely anaerobic photosynthesis

2005

272. Epigenetic control of gene expression in plants relies on modifications to chromatin structure. Which modification is universally associated with the activation of gene transcription?
(A) Trimethylation of Histone H3 at Lysine 4 (H3K4me3)
(B) Hypermethylation of cytosine residues at promoter regions
(C) Deacetylation of core histone N-terminal tails
(D) Dissociation of nucleosomes from the chromosome

2013

273. An advantage of utilizing RNA-seq over traditional microarray technology for transcriptomic analysis is that RNA-seq allows:
(A) Discovery of novel splice variants without prior knowledge
(B) Use of identical DNA templates
(C) Precise detection of extremely highly expressed genes
(D) Direct measurement of un-spliced pre-mRNA

2010

274. The PacBio Sequel system unique advantage lies in its capacity to:
(A) Generate exceptionally long, continuous single-molecule reads
(B) Generate billions of short 50-base pair reads
(C) Rely exclusively on protein nanopore disruptions
(D) Sequence only the methyl groups of DNA

NODIA

2004

297. During Agrobacterium-mediated transformation, which plant-derived signaling molecules activate the bacterial vir genes?
(A) Phenolic compounds such as acetosyringone
(B) Abscisic acid and Jasmonic acid
(C) Complex structurally intact starches
(D) Highly structured viral DNA

2012

298. The phenomenon where the progeny of two genetically diverse parents exhibit greater biological vigor or yield than either parent is known as:
(A) Heterosis
(B) Inbreeding depression
(C) Genetic drift
(D) Linkage disequilibrium

2014

299. The Sanger method of DNA sequencing relies fundamentally on the incorporation of which specific molecules to terminate chain elongation?
(A) Dideoxynucleoside triphosphates (ddNTPs)
(B) Deoxynucleoside triphosphates (dNTPs)
(C) Fluorescently labeled amino acids
(D) Ribonucleoside triphosphates

2024

300. In the CRISPR/Cas9 system, which component is responsible for guiding the Cas9 nuclease to a specific target DNA sequence?
(A) Single guide RNA (sgRNA)
(B) PAM sequence
(C) DNA polymerase
(D) Reverse transcriptase

****

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2010

285. The progression of the eukaryotic cell cycle is primarily regulated by the periodic synthesis and degradation of which specific proteins?
(A) Cyclins
(B) Actin
(C) Tubulin
(D) RuBisCO

2023

286. Phytochromes are plant photoreceptors that primarily perceive and respond to which wavelengths of light?
(A) Red and far-red light
(B) Blue and ultraviolet light
(C) Green and yellow light
(D) Infrared light exclusively

2021

287. MicroRNAs are initially transcribed by RNA Polymerase II. What structural feature of this transcript is recognized by Dicer-Like (DCL) enzymes?
(A) Imperfectly base-paired stem-loop hairpins
(B) A perfect single-stranded circular loop
(C) A strictly unmethylated TATA box
(D) A massive poly-G tract

2016

288. The conservation of gene order and orientation between the genomes of two different species is defined as:
(A) Synteny
(B) Epistasis
(C) Pleiotropy
(D) Heterosis

2003

289. An organism that possesses more than two complete sets of chromosomes derived from the same species is specifically termed an:
(A) Autopolyploid
(B) Allopolyploid
(C) Aneuploid
(D) Haploid

2004

290. Which molecular technique is traditionally used to detect the presence and quantity of a specific RNA molecule within a complex mixture?
(A) Northern blotting
(B) Southern blotting
(C) Western blotting
(D) Eastern blotting

2012

291. Which genomic phenomenon describes the observation that the number of protein-coding genes does not necessarily scale with genome size or organismal complexity?
(A) Gene density variation
(B) Polyploidy
(C) Epigenetic silencing
(D) Alternative splicing

2024

292. In C4 plants, the initial fixation of atmospheric carbon dioxide occurs in the mesophyll cells and is catalyzed by which enzyme?
(A) PEP carboxylase
(B) Rubisco
(C) Pyruvate kinase
(D) ATP synthase

2015

293. Which structural feature distinguishes eukaryotic nuclear genes from those in plastid or mitochondrial genomes?
(A) Possessing introns that require complex splicing
(B) Nuclear genes are strictly polycistronic
(C) Nuclear genes lack promoters
(D) Nuclear genes are only transcribed in the dark

2012

294. Which molecule, synthesized from ATP by adenylyl cyclase, acts as a ubiquitous second messenger in various signaling pathways?
(A) Cyclic AMP (cAMP)
(B) Glucose-6-phosphate
(C) Pyruvate
(D) Lactic acid

2003

295. Variegated leaf patterns in Mirabilis jalapa (four o'clock plant) provided the first evidence for which genetic phenomenon?
(A) Cytoplasmic (plastid) inheritance
(B) Mendelian dominance
(C) Incomplete dominance
(D) Sex-linked inheritance

NODIA

2010

296. The ability of a single tRNA species to recognize and bind to multiple codons that differ only at the third base position is explained by the:
(A) Wobble hypothesis
(B) Central dogma
(C) Genetic code degeneracy
(D) Frame shift mutation

2012

275. Heat Shock Proteins (HSPs) function as molecular chaperones. During abiotic heat stress, their primary protective role is to:
(A) Prevent irreversible aggregation and assist in refolding
(B) Directly destroy targeted proteins
(C) Provide a protective shell around the nucleus
(D) Halt all cellular transcription

2022

276. Plant specific receptor-like kinases (RLKs) structurally consist of:
(A) Extracellular binding, transmembrane helix, and intracellular kinase domains
(B) An entirely cytoplasmic set of non-membrane associated proteins
(C) A series of six transmembrane helices without an extracellular domain
(D) A single massive subunit encoded exclusively by the chloroplast

2024

277. The targeted degradation of the AUX/IAA repressor proteins is dependent on:
(A) Ubiquitination by the SCF^TIR1 complex after auxin binding
(B) Their direct binding to the thylakoid membrane
(C) The synthesis of completely novel DNA sequences
(D) Passive diffusion through the nuclear pore

2025

278. MicroRNAs (miRNAs) in plants induce targeted transcript cleavage because:
(A) Shared complementarity promotes AGO1-mediated slicing
(B) They bind to the poly-A tail to prevent translation
(C) They physically delete the gene from the genomic DNA
(D) They prevent mRNA export by blocking the nuclear pore

2013

279. In proteomic analysis, two-dimensional gel electrophoresis (2D-PAGE) separates proteins based on which two physical properties?
(A) Isoelectric point and molecular mass
(B) Hydrophobicity and total sugar content
(C) Solubility and lipid binding affinity
(D) Nucleic acid content and phosphorylation state

2009

280. Which bioinformatics tool is most commonly used to compare a primary DNA or protein sequence against a database to identify regions of similarity?
(A) BLAST
(B) Clustal Omega
(C) RasMol
(D) PyMOL

2017

281. In quantitative genetics, the primary advantage of utilizing genome-wide SNP arrays is that they:
(A) Provide high-density saturated coverage for precise QTL mapping
(B) Eliminate the need to measure the plant's actual phenotype
(C) Permanently cure genetic defects found in the population
(D) Identify mutations that only occur in the chloroplast genome

2015

282. The structural integrity of the chromosome is protected at its ends by telomeres. Telomeric DNA sequences in plants are characterized by:
(A) Long GC-rich tandemly repeated sequences
(B) Highly transcribed single-copy housekeeping genes
(C) Blocks of AT-rich ribosomal RNA genes
(D) Inverted repeats mimicking the chloroplast genome

2006

283. During the transcription of a eukaryotic nuclear gene, which specific sequence signals the end of the transcript?
(A) The highly conserved Polyadenylation signal sequence
(B) The TATA box
(C) The ATG start codon
(D) The 5' UTR Kozak sequence

2011

284. The transcription factor family most intimately involved in regulating the response to extreme dehydration is:
(A) DREB (Dehydration Responsive Element Binding)
(B) WUSCHEL (WUS)
(C) CONSTANS (CO)
(D) LEAFY (LFY)

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ANSWERS

1. (B) Nucleosome
Nucleosomes consist of DNA wrapped around an octamer of histone proteins. This beads-on-a-string structure is essential for compacting genetic material within the nucleus. Each unit contains approximately 147 base pairs of DNA. The histone core includes two copies each of H2A, H2B, H3, and H4. This organization facilitates gene regulation and protects genomic integrity during cell division.

2. (D) Total haploid DNA content
The C-value paradox observes that genomic size does not correlate with an organism's biological complexity. Some simple organisms possess significantly larger genomes than more complex species like humans. This discrepancy is primarily due to the accumulation of non-coding repetitive DNA, such as retrotransposons. Understanding this phenomenon highlights the evolutionary processes that shape genomic architecture across various biological lineages.

3. (A) Large inverted repeats separating single-copy regions
Chloroplast genomes in most land plants display a quadripartite structure consisting of two large inverted repeats. These repeats separate the large single-copy and small single-copy regions. This unique arrangement provides structural stability and promotes intramolecular recombination. The presence of these repeats ensures that genes within them are present in duplicate copies, contributing to high sequence conservation levels.

4. (C) Homologous recombination across large repeat sequences
Plant mitochondrial genomes are characterized by a complex multipartite structure formed through frequent recombination events. Large identical repeat sequences facilitate intramolecular homologous recombination, which results in the fragmentation of the master circle into various subgenomic circular molecules. This dynamic structural variability is a hallmark of plant mitochondria, allowing for rapid genomic rearrangements despite a slow rate of nucleotide sequence evolution.

5. (B) Upstream at position -30
The TATA box is a highly conserved cis-regulatory element found within the core promoter of many eukaryotic nuclear genes. It typically resides approximately 25 to 30 base pairs upstream of the transcription start site. This specific sequence serves as the binding site for the TATA-binding protein, which recruits the general transcription machinery. Its precise positioning is critical for accurate initiation.

6. (D) AAUAAA
In eukaryotic messenger RNA processing, the polyadenylation signal is a highly conserved hexanucleotide sequence located in the 3' untranslated region. The sequence AAUAAA is recognized by specific endonucleases that cleave the nascent transcript downstream. Following cleavage, poly-A polymerase adds a tail of adenine residues. This modification is essential for transcript stability, nuclear export, and efficient translation initiation during protein synthesis.

7. (B) Transcriptional activator
Transcriptional activators are specific proteins that bind to enhancer sequences to increase the rate of gene transcription. These trans-acting factors possess distinct DNA-binding domains and activation domains. They often interact with the mediator complex or general transcription factors to recruit RNA polymerase to the promoter. This mechanism allows for precise spatial and temporal control of gene expression across different tissues.

8. (C) Distinct enhancer or silencer elements
Tissue-specific gene expression is primarily regulated by the interaction between unique trans-acting transcription factors and specific cis-regulatory elements. Enhancers and silencers located near or far from the target gene dictate the transcriptional activity in particular cell types. These elements respond to developmental cues and environmental signals, ensuring that the necessary proteins are synthesized only where and when required biologically.

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(D) Chloroplast photosystem II complex

2017

254. Calcium ions ($Ca^{2+Cus \longrightarrow m}$) function as secondary messengers. In plant cells, the major defined intracellular stores for releasable calcium are:
(A) Vacuole and endoplasmic reticulum
(B) Nucleoplasm and nucleolus
(C) Inner thylakoid space
(D) Extracellular cell wall matrix

2012

255. The regulatory mechanism governing auxin signaling relies on hormone perception linking to the destruction of which negative repressor?
(A) AUX/IAA
(B) DELLA
(C) JAZ
(D) MYC2

2002

256. Endogenous small RNAs load into Argonaute proteins to execute gene silencing. The formed effector complex is known as:
(A) The RISC (RNA-Induced Silencing Complex)
(B) The Spliceosome
(C) The Proteasome
(D) The Exosome

2018

257. Post-Transcriptional Gene Silencing (PTGS) recognizes double-stranded RNA as an abnormal signature. This indicates that PTGS evolved as a defense against:
(A) RNA viral infections
(B) Heavy metal toxicity
(C) Excessive sunlight exposure
(D) Nutrient starvation

2007

258. Single Nucleotide Polymorphism (SNP) markers are favored because they offer bi-allelic discrimination. SNPs differ from standard SSR markers because:
(A) SNPs rely on single base changes
(B) SNPs are dominant, while SSRs are co-dominant
(C) SNPs can only be scored using radioactive isotopes
(D) SNPs only occur on the Y chromosome

2005

259. When conducting Marker-Assisted Backcrossing (MABC), utilizing markers tightly linked to the trait of interest constitutes:
(A) Foreground selection
(B) Background selection
(C) Recombinant selection
(D) Random phenotypic selection

2014

260. The fundamental unit of chromatin structure, the nucleosome, consists of:
(A) 147 bp of DNA wrapped around an octamer of histones
(B) 147 bp of DNA wrapped around a single histone H1 protein
(C) 147 bp of DNA enclosed inside a hollow lipid micelle
(D) A straight, unbound double helix

2012

261. Transposable elements drive C-value variation in plants. Which element frequently accumulates into nested blocks?
(A) Ty1-copia and Ty3-gypsy LTR retroelements
(B) Short structured MITEs
(C) Single-copy structural genes
(D) Infectious DNA viruses

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2012

262. The dominant structural feature separating chloroplast genomes from most plant mitochondrial genomes is the presence of:
(A) Inverted repeats partitioning single-copy regions
(B) A perfectly linear sequence
(C) A lack of any functional genes
(D) Frequent massive structural rearrangements

2017

263. RNA editing in plant mitochondria corrects inappropriate codons. Which biochemical substitution characterizes the majority of mitochondrial RNA editing events?
(A) Cytidine to Uridine
(B) Guanosine to Adenosine
(C) Adenosine to Inosine
(D) Uridine deletion

2001

264. The functional fine structure of active eukaryotic genes features a polyadenylation signal sequence located in which specific region?
(A) Within the 3' Untranslated Region (3' UTR)
(B) The middle of the first intron
(C) Upstream of the transcription start site
(D) Overlapping the ATG start codon

18. (A) Auxin signaling
Auxin signaling pathways regulate plant growth and development by controlling the activity of various transcription factors. This mechanism depends on the hormone-induced degradation of AUX/IAA repressor proteins via the ubiquitin-proteasome system. When auxin is present, it facilitates the interaction between these repressors and an E3 ubiquitin ligase, leading to their destruction and allowing for the expression of auxin-responsive genes.

19. (C) Directing mRNA cleavage or translational repression
MicroRNAs in plants are small, non-coding RNA molecules that play a pivotal role in post-transcriptional gene regulation. They function by guiding an effector complex to complementary messenger RNA sequences. Depending on the degree of base pairing, the microRNA directs the cleavage of the target transcript or inhibits its translation. This mechanism allows for the precise fine-tuning of gene expression levels.

20. (A) I, II and IV
The RNA interference pathway is a conserved mechanism used for gene silencing and defense against viruses. Dicer enzymes process long double-stranded RNA into short interfering RNAs, which then guide the RNA-induced silencing complex to complementary targets. Argonaute proteins within this complex act as the catalytic components that cleave the target messenger RNA. This pathway results in the specific downregulation.

21. (B) RAPD
Random Amplified Polymorphic DNA markers utilize short, non-specific primers to amplify arbitrary genomic regions via polymerase chain reaction. This technique does not require prior knowledge of the target genome's sequence. The resulting DNA profiles are used to assess genetic diversity and map loci. Because the primers are arbitrary, the markers are typically inherited in a dominant fashion in various genetic studies.

22. (D) It must be tightly linked to the target gene or quantitative trait locus.
Marker-assisted selection utilizes molecular markers to identify and select individuals possessing desirable traits. For this method to be effective, the marker must be located in close physical proximity to the target gene or quantitative trait locus. High levels of linkage disequilibrium ensure that the marker and the gene are inherited together, allowing breeders to predict the phenotype accurately.

23. (B) 147 base pairs
The nucleosome is the fundamental repeating unit of eukaryotic chromatin, consisting of a protein core surrounded by genetic material. In the core particle, approximately 147 base pairs of DNA are wrapped nearly twice around an octamer of histone proteins. This compact structure facilitates the efficient packaging of the genome within the nucleus and plays a significant role in regulation.

24. (C) Retrotransposons
Retrotransposons are a major class of transposable elements that increase their copy number within a genome through a copy-and-paste mechanism. This process involves the transcription of the element into an RNA intermediate, which is then reverse-transcribed back into DNA by a specialized enzyme. The new DNA copy is subsequently integrated into a different genomic location, contributing to genome size.

25. (C) Ribosomal RNA
The chloroplast genome typically contains two large inverted repeat regions that are identical in sequence but opposite in orientation. These regions are characterized by the presence of genes encoding ribosomal RNAs, which are essential for the assembly of plastid ribosomes. This duplicated arrangement ensures high levels of ribosomal RNA production, supporting the extensive protein synthesis required for photosynthetic processes.

26. (D) RNA editing
RNA editing is a post-transcriptional process that alters the nucleotide sequence of transcripts in plant organelles. In mitochondria, this phenomenon predominantly involves the conversion of specific cytidine residues to uridine. This modification often corrects potential mutations, ensuring that the resulting proteins are functional. It is vital for the proper expression of genes involved in oxidative phosphorylation and energy production.

27. (A) Translation initiation and efficiency
The 5' untranslated region of a eukaryotic messenger RNA is the sequence located between

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the polymerase, a proton is released, causing a detectable change in pH. This signal is then converted into a sequence read.

83. (A) Drought and cold stress
The Dehydration Responsive Element Binding transcription factors play a pivotal role in plant stress tolerance. These factors are induced in response to various abiotic challenges, particularly drought and cold stress. They function by binding to specific cis-elements in the promoters of stress-responsive genes. By activating a broad range of protective proteins, DREB transcription factors enhance the plant's ability.

84. (A) Auxin
Auxin signaling is initiated when the hormone binds directly to the TIR1 receptor, which is a component of an E3 ubiquitin ligase complex. This binding facilitates the interaction between the receptor and AUX/IAA repressor proteins, leading to their ubiquitination and subsequent degradation by the proteasome. The removal of these repressors allows auxin-responsive transcription factors to activate the expression of genes.

85. (B) Phosphatases (PP2Cs)
Abscisic acid signaling is essential for plant responses to water deficit and other stresses. The pathway relies on PYR/PYL/RCAR receptors, which bind ABA to initiate the response. Upon binding the hormone, these receptors physically interact with and inhibit type 2C protein phosphatases. This inhibition allows downstream kinases to remain active, leading to the phosphorylation of transcription factors and transporters.

86. (A) siRNAs derive from dsRNA precursors; miRNAs derive from hairpins.
Plant small interfering RNAs and microRNAs are distinguished primarily by their biogenesis pathways and precursors. MicroRNAs are derived from single-stranded primary transcripts that fold into characteristic hairpin structures. In contrast, small interfering RNAs originate from long, double-stranded RNA molecules that may be endogenous or exogenous in origin. Both types of small RNAs then guide specific gene silencing mechanisms.

87. (C) The guide strand
The assembly of the RNA-induced silencing complex is a critical step in the RNA interference pathway. This process involves the loading of a short, double-stranded RNA molecule into the complex, followed by the removal of one strand. The remaining strand, known as the guide strand, provides the sequence specificity required to target complementary messenger RNA transcripts for cleavage.

88. (B) Restriction digestion and PCR amplification
Amplified Fragment Length Polymorphism is a highly reproducible molecular marker technique used for genomic analysis. It combines the principles of restriction enzyme digestion and polymerase chain reaction amplification. DNA is first cleaved by enzymes, and then specific adapters are ligated. Subsequent selective PCR amplification of these fragments generates a unique fingerprint. This method is valuable for genetic mapping and diversity.

89. (B) They represent the most abundant source of sequence variation in genomes.
Single Nucleotide Polymorphisms are the most abundant source of sequence variation in plant genomes, making them ideal markers for high-resolution diversity analysis. They represent variations at a single base position and are widely distributed across both coding and non-coding regions. Due to their high frequency and stability, SNPs provide the resolution necessary for genome-wide association studies and precise mapping.

90. (A) Both A and R are true and R is the correct explanation of A.
PacBio single-molecule real-time sequencing is classified as a third-generation technology because it sequences individual molecules directly and in real-time. Unlike second-generation platforms, it does not require pre-amplification by PCR, which reduces potential biases and allows for the detection of base modifications. This approach enables the generation of exceptionally long reads, which are essential for assembling complex genomic regions.

91. (A) It is transcriptionally active and less condensed.
Euchromatin and heterochromatin represent two distinct functional states of chromatin in the eukaryotic nucleus. Euchromatin is characterized

NODIA

is essential for validating the functions of genes discovered during sequencing.

37. (B) PacBio SMRT sequencing
Single-molecule real-time sequencing technology, developed by PacBio, is characterized by its ability to generate exceptionally long reads. This platform utilizes zero-mode waveguides to monitor the activity of an immobilized DNA polymerase in real-time. By capturing fluorescent signals as each nucleotide is incorporated, the system can sequence single molecules directly. This approach is highly effective for assembling complex genomic regions.

38. (B) Water deficit (drought)
Late Embryogenesis Abundant proteins are a diverse group of highly hydrophilic molecules that accumulate in seeds during maturation and in vegetative tissues during stress. They primarily confer tolerance against water deficit or drought by acting as molecular chaperones. These proteins stabilize cellular structures, prevent the denaturation of other proteins, and protect membranes from damage caused by severe dehydration.

39. (A) Alpha subunit and beta-gamma dimer
Heterotrimeric G-proteins are integral components of many cell signaling pathways. They consist of three distinct subunits: alpha, beta, and gamma. Upon activation by a G-protein-coupled receptor, the alpha subunit exchanges GDP for GTP and dissociates from the beta-gamma dimer. Both the activated alpha subunit and the beta-gamma dimer can then interact with various effector proteins to transmit.

40. (A) Both A and R are true and R is the correct explanation of A.
Multiple plant hormone signaling pathways utilize a common regulatory theme involving the targeted degradation of repressor proteins. For instance, auxin and gibberellin initiate signaling by triggering the ubiquitin-proteasome-mediated destruction of repressors like AUX/IAA and DELLA. This removal allows for the activation of transcription factors that drive hormone-responsive gene expression. This mechanism provides a rapid and efficient cellular response.

41. (A) RNA Polymerase II
The biogenesis of plant microRNAs begins with the transcription of long primary transcripts called pri-miRNAs. This process is catalyzed by nuclear RNA Polymerase II, the same enzyme responsible for synthesizing messenger RNAs. These primary transcripts feature a characteristic hairpin structure that is subsequently recognized and processed by Dicer-like enzymes. The resulting mature microRNAs then function as key regulators.

42. (D) Small interfering RNAs (siRNAs)
Systemic acquired silencing is a phenomenon where the gene-silencing effect initiated in one part of the plant spreads throughout the entire organism. This process is mediated by a mobile signal that traverses the vascular system. Small interfering RNAs are the primary molecules believed to act as this signal. By traveling through plasmodesmata and the phloem, they guide silencing in distant.

43. (A) Codominant inheritance
Simple Sequence Repeats are highly effective molecular markers for plant genetic mapping due to several unique properties. They exhibit co-dominant inheritance, meaning they can distinguish between homozygous and heterozygous individuals at a specific locus. Furthermore, their high levels of polymorphism and wide genomic distribution make them invaluable for diversity analysis and the construction of high-density linkage maps in breeding.

44. (C) High-density phenotypic evaluation data
The identification of quantitative trait loci is a fundamental process in plant genetics that seeks to link specific genomic regions with complex traits. This requires the integration of high-density marker genotypic data with precise phenotypic evaluation data. By statistically correlating these datasets across a mapping population, researchers can locate the loci responsible for variations in traits such as yield.

45. (A) H1
The structural organization of chromatin involves several histone proteins. The nucleosome octamer consists of two copies each of histones H2A, H2B, H3, and H4, around which the DNA is wrapped. Histone H1, known as the linker histone, is not part of this core particle. Instead,

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it binds to the linker DNA between nucleosomes, facilitating the further condensation of fibers.

46. (D) Tandem satellite repeats
Plant genomes contain large amounts of repetitive DNA, particularly in specialized regions like centromeres and telomeres. These areas are predominantly composed of tandem satellite repeats, which consist of short sequence motifs repeated many thousands of times in a head-to-tail fashion. These structural elements are essential for maintaining chromosomal integrity and ensuring proper segregation during mitosis and meiosis in plants.

47. (B) A circular double-stranded DNA molecule
The plastome, or chloroplast genome, is typically organized as a circular, double-stranded DNA molecule. This structure is highly conserved across most land plant species. The genome contains genes essential for photosynthesis and plastid-specific processes. Its circular nature provides structural stability and facilitates efficient replication within the organelle, reflecting its ancient endosymbiotic bacterial origin and evolutionary history in plants.

48. (C) Multipartite variable structure
Plant mitochondrial genomes are remarkably complex and differ significantly from their animal counterparts. Due to frequent homologous recombination across large repeat sequences, the genome exists as a multipartite variable structure rather than a single stable circle. This organization consists of a collection of subgenomic molecules that can coexist within the organelle. This structural fluidity is a defining characteristic of mitochondria.

49. (D) GT
During the process of eukaryotic pre-messenger RNA splicing, the boundaries between exons and introns are strictly defined by highly conserved sequences. The 5' splice site, which marks the beginning of an intron, almost invariably starts with the dinucleotide GT. This sequence is recognized by the spliceosomal machinery to ensure the precise removal of the intron and the correct ligation.

50. (A) P-4, Q-2, R-3, S-1
DNA sequencing platforms utilize diverse biochemical principles to determine genetic codes. Sanger sequencing employs dideoxynucleotide chain termination, while Illumina relies on reversible dye terminators. PacBio technology uses single-molecule real-time synthesis within zero-mode waveguides. Oxford Nanopore represents a unique approach by measuring disruptions in electrical current as single molecules pass through protein pores. These chemistries provide varying read lengths.

51. (B) The 5' triphosphate end
The addition of a 7-methylguanosine cap is a critical step in eukaryotic messenger RNA processing. This modification occurs at the 5' triphosphate end of the nascent transcript shortly after the initiation of transcription. The cap structure is essential for protecting the mRNA from degradation by exonucleases, facilitating nuclear export, and ensuring the efficient recognition of the transcript by ribosomes.

52. (C) They function independently of orientation or distance from the start site.
Enhancers are distinct cis-regulatory elements that play a vital role in upregulating gene expression. Unlike typical core promoters, enhancers can function independently of their orientation and can be located at significant distances from the transcription start site. They operate by providing binding sites for transcriptional activators, which then interact with the promoter through DNA looping and the mediator complex.

53. (A) Using a phaseolin or oleosin promoter
To ensure that a transgene is expressed only during specific developmental stages, such as seed maturation, researchers utilize tissue-specific promoters. Phaseolin and oleosin promoters are classic examples of such regulatory elements that are highly active in seeds. By driving the transgene with these promoters, the expression can be strictly confined to the target tissue, avoiding unwanted effects elsewhere.

54. (B) From proplastid to mature photosynthetic chloroplast
Chloroplast development involves a transition in the usage of two distinct RNA polymerases. Early in development, during the proplastid stage, the nuclear-encoded polymerase is primarily active, transcribing genes for the plastid's genetic machinery. As the organelle matures into a photosynthetic chloroplast, the plastid-encoded polymerase becomes dominant. This switch is

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essential for the high-level expression of genes encoding photosynthetic apparatus.

55. (B) T-urf13
Cytoplasmic male sterility in the Texas (T) cytoplasm of maize is caused by a specific mutation in the mitochondrial genome. This mutation resulted in the formation of a novel chimeric gene known as T-urf13. The protein product of this gene localizes to the mitochondrial membrane and interferes with normal function, leading to the failure of pollen development in plants.

56. (D) Preventing the accumulation of unbound Rubisco small subunits
The coordinate expression of the rbcL and rbcS genes is essential for the efficient assembly of the Rubisco holoenzyme. Because the subunits are encoded in different cellular compartments, the plant must synchronize their production. Proper stoichiometry ensures that neither large nor small subunits accumulate in an unbound state, which could be detrimental to the cell or lead to waste.

57. (B) Oxygen
The nitrogenase enzyme complex, responsible for biological nitrogen fixation, is extremely sensitive to the presence of oxygen. This molecule irreversibly inactivates the enzyme by damaging its metal-containing cofactors. Consequently, diazotrophic organisms have evolved various strategies to protect nitrogenase, such as high respiration rates or specialized proteins like leghemoglobin, which buffer oxygen levels within the nodules to maintain activity.

58. (C) ATP-dependent chromatin remodeling
The SWI/SNF complex is a major class of epigenetic regulators that play a vital role in controlling gene expression. These complexes utilize the energy derived from ATP hydrolysis to physically reposition or restructure nucleosomes along the DNA. By altering the accessibility of specific genomic regions, the SWI/SNF complex allows transcription factors and the transcriptional machinery to reach the target sites.

59. (D) Total messenger RNAs
Transcriptomics is a fundamental field of functional genomics that focuses on the comprehensive analysis of the transcriptome. By quantifying the abundance of total messenger RNAs within a cell at a specific time or under particular conditions, researchers can gain insights into the dynamic regulatory state of the organism. This approach provides a snapshot of gene activity and cellular responses.

60. (A) Library preparation → Bridge amplification → Sequencing by synthesis → Data analysis
The Illumina sequencing workflow follows a strict sequence of fundamental steps to generate high-quality genomic data. It begins with library preparation, where DNA is fragmented and adapters are ligated. This is followed by bridge amplification on a flow cell to create clonal clusters. The actual sequencing occurs via the synthesis of complementary strands with fluorescent terminators, followed by analysis.

61. (D) HSE (Heat Shock Elements)
Under high-temperature stress, plants activate a specific set of protective genes encoding heat shock proteins. This response is mediated by heat shock transcription factors, which recognize and bind to conserved cis-elements known as heat shock elements. These elements are typically located in the promoter regions of target genes. Upon binding, the transcription factors trigger the rapid upregulation of chaperones.

62. (A) Inositol 1,4,5-trisphosphate (IP3)
Secondary messengers are small molecules that relay signals from receptors on the cell surface to target molecules inside the cell. In plant signaling pathways, inositol 1,4,5-trisphosphate is a major secondary messenger. It is produced in response to specific extracellular stimuli and triggers the release of calcium ions from intracellular stores, thereby initiating various physiological and developmental responses within the cell.

63. (B) They serve as repressors that bind to and inhibit MYC transcription factors.
The jasmonate signaling pathway is critical for plant defense and development. In this pathway, members of the JAZ protein family function as negative repressors. They bind to and inhibit the activity of MYC transcription factors, preventing the expression of jasmonate-responsive genes. When jasmonic acid levels rise, these repressors are targeted for degradation, allowing the transcription factors to activate the response.

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64. (D) RISC
In plant cells, mature microRNAs are integrated into a specialized effector complex known as the RNA-induced silencing complex. This complex is responsible for executing the gene-silencing instructions carried by the small RNA. By guiding the complex to complementary messenger RNA sequences, the microRNA facilitates the cleavage or translational repression of the target transcript, thereby effectively regulating the activity of the gene.

65. (D) Double-stranded RNA
Post-transcriptional gene silencing is a fundamental defense and regulatory mechanism triggered by the presence of double-stranded RNA within the cell. This anomalous nucleic acid structure is recognized by specialized enzymes, such as Dicer, which process it into small interfering RNAs. These small RNAs then initiate the sequence-specific degradation of complementary messenger RNA transcripts, resulting in the silencing of the target gene.

66. (B) Restriction endonucleases
Restriction Fragment Length Polymorphism markers are based on variations in the DNA sequence that affect the recognition sites of restriction endonucleases. These enzymes cleave the DNA at specific sequences, generating fragments of various lengths. By analyzing the resulting patterns, researchers can identify genetic variations between individuals. This technique was among the first molecular methods used for genetic mapping and diversity analysis.

67. (B) Marker-Assisted Backcrossing (MABC)
Marker-assisted backcrossing is a precise breeding methodology used to introgress a specific desirable trait from a donor parent into an elite recurrent parent. This process utilizes molecular markers to select for the target trait while simultaneously selecting against the donor genome at other loci. This allows for the rapid recovery of the recurrent parent's genetic background across the entire genome.

68. (C) 30 nm
The structural organization of chromatin in the eukaryotic nucleus involves multiple levels of condensation. The fundamental "beads-on-a-string" fiber, which has a diameter of approximately 10 nanometers, is further coiled and packed into a more compact structure. This secondary fiber typically exhibits an estimated diameter of 30 nanometers. This structural level is essential for the efficient storage of DNA.

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69. (C) Long interspersed nuclear elements (LINEs)
Repetitive genomic DNA can be classified into tandemly arrayed or interspersed repeats. Interspersed repeats are scattered throughout the genome rather than being clustered in a single location. Long interspersed nuclear elements, or LINEs, are a prime example of this category. These autonomous retrotransposons contribute significantly to genome expansion and structural diversity across many plant species by integrating into diverse loci.

70. (A) I, IV, II, III
A typical eukaryotic gene is organized into several functional elements arranged in a specific physical order from the 5' to the 3' end. The sequence begins with the promoter region, followed by the 5' untranslated region. The start codon marks the beginning of the protein-coding sequence. Finally, the polyadenylation signal is located at the 3' end, dictating transcript termination.

71. (C) Repeat pairs
The multipartite structure of the plant mitochondrial genome is primarily facilitated by the presence of large regions of identical sequence. These repeat pairs provide sites for high-frequency homologous recombination. Intramolecular recombination across these sequences continually rearranges the genome, breaking the master circle into various subgenomic molecules. This dynamic structural variability is a key characteristic that distinguishes plant mitochondria from other organelles.

72. (A) The poly(A) tail
The poly(A) tail is a crucial structural component of mature eukaryotic messenger RNA that is added post-transcriptionally to the 3' end. This sequence, consisting of a long tract of adenine residues, protects the transcript from exonuclease degradation and enhances its stability within the cytoplasm. Additionally, it plays an essential role in nuclear export and the initiation of translation.

73. (B) TATA box
The TATA box is a fundamental core promoter element that plays a central role in the initiation

of eukaryotic nuclear transcription. It provides the specific binding site for the TATA-binding protein, which is a component of the general transcription factor TFIID. The binding of TBP to the TATA box is the initial step in assembling the transcription pre-initiation complex.

74. (D) Helix-turn-helix
The helix-turn-helix is a specialized DNA-binding motif common in many transcription factors. It is characterized by two alpha helices separated by a short beta turn. One of these helices acts as the recognition helix, which securely docks into the major groove of the DNA double helix to recognize specific nucleotide sequences. This motif allows for stable and sequence-specific interactions.

75. (D) GUS (uidA)
The GUS reporter gene, which encodes the enzyme beta-glucuronidase, is widely used in plant biotechnology to assay promoter activity. When fused to a promoter and introduced into a plant, the expression of GUS can be visually detected through histochemical staining. This process produces a blue color in tissues where the promoter is active, allowing researchers to study patterns.

76. (B) Anterograde signaling
Chloroplast function and development are tightly regulated by signaling between the nucleus and the organelle. Anterograde signaling refers to the transmission of regulatory information from the nucleus to the chloroplast. An example of this is the nuclear control of the plastid's transcription machinery, such as the targeting of nuclear-encoded polymerase to the plastid early in plant development.

77. (A) Modifying or degrading the toxic mitochondrial transcripts
Nuclear restorer genes are essential for overcoming the effects of cytoplasmic male sterility in plants. These genes function primarily by neutralizing the toxic products of mitochondrial mutations. Most Rf genes encode proteins that target specific mitochondrial transcripts, leading to their modification or degradation. By preventing the accumulation of these harmful proteins, the restorer genes ensure that normal pollen development occurs.

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78. (D) It requires chaperonins for proper folding and assembly.
The Rubisco enzyme complex possesses several unique genetic and structural features. Due to its large size and complexity, the assembly of the functional holoenzyme is a highly demanding process. It requires the assistance of specialized molecular chaperonins within the chloroplast stroma to prevent aggregation and ensure the correct folding of the subunits. This coordination is vital for maintaining photosynthesis.

79. (B) Nitrogen
In rhizobial nitrogen fixation, the expression of nitrogenase-encoding genes is tightly regulated by environmental conditions. When high concentrations of combined nitrogen, such as ammonia or nitrate, are present in the soil, the expression of the nif genes is repressed. This ensures that the bacteria do not expend significant energy on the costly process of nitrogen fixation when nitrogen is available.

80. (D) CAU
Cytosine methylation in plant genomes is a critical epigenetic modification that occurs in several distinct sequence contexts. These include the symmetric CG and CHG contexts, as well as the asymmetric CHH context, where H represents any nucleotide except guanine. These patterns are maintained by specific methyltransferase families. The sequence CAU is not a recognized context for DNA methylation in plants.

81. (A) Generating and analyzing a knockout mutant for the gene
To definitively validate the biological function of an uncharacterized gene, researchers often employ a reverse genetics approach. By generating and analyzing a knockout mutant, where the gene's function is completely abolished, the resulting changes in the organism's phenotype can be observed. This comparison between the mutant and the wild-type provides direct evidence of the gene's essential role.

82. (A) Ion Torrent
Ion Torrent is a next-generation sequencing technology that utilizes a unique semiconductor-based detection method. Unlike platforms that rely on fluorescence, this technology directly measures the release of hydrogen ions during DNA synthesis. As each nucleotide is incorporated by

signaling is regulated by the BIN2 kinase. These mechanisms ensure that hormonal responses are tightly controlled through targeted proteolysis.

101. (A) Dinitrogenase (MoFe protein)
The nitrogenase enzyme complex is composed of two primary proteins: dinitrogenase and dinitrogenase reductase. Dinitrogenase, also known as the MoFe protein, contains the unique iron-molybdenum cofactor that serves as the catalytic site for the reduction of atmospheric dinitrogen to ammonia. This cofactor is essential for the enzyme's function and is protected from oxygen during the fixation process.

102. (B) DNA methyltransferases (MET1)
In plant epigenetics, the maintenance of DNA methylation is crucial for preserving gene silencing patterns during cell division. The MET1 family of DNA methyltransferases is specifically responsible for maintaining cytosine methylation in the symmetric CG context during semi-conservative replication. By recognizing hemimethylated DNA, these enzymes ensure that the epigenetic information is accurately inherited by the daughter strands.

103. (B) RNA sequencing (RNA-seq)
RNA sequencing is a powerful functional genomics technique designed to measure the comprehensive expression levels of thousands of mRNA transcripts simultaneously. By converting the total RNA population into a library of DNA fragments and sequencing them using high-throughput platforms, researchers can quantify transcript abundance and identify novel splice variants. This provides a detailed snapshot of the cell's regulatory state.

104. (A) Substitution errors driven by optical phasing and pre-phasing issues
Standard Illumina sequencing platforms are highly accurate but can produce specific artifacts during the process. The most common errors are substitution errors, which are often driven by optical phasing and pre-phasing issues. This occurs when some molecules in a cluster fail to incorporate a nucleotide or incorporate multiple, leading to a loss of signal synchrony and reduced call quality.

105. (A) Heat Shock Proteins (HSPs)
Abiotic stress responses in plants often converge on the synthesis of protective chaperone proteins. The heat shock protein family consists of these molecular chaperones, which are induced by high temperatures and other stressors. Their primary role is to prevent the denaturation and irreversible aggregation of cellular proteins, as well as to assist in the refolding of damaged molecules.

106. (B) Hydrolysis of GTP to GDP
In G-protein coupled signaling pathways, the G-alpha subunit acts as a molecular switch. It is active when bound to GTP and inactive when bound to GDP. The active signaling state is terminated when the alpha subunit hydrolyzes the bound GTP to GDP. This biochemical action leads to the re-association of the alpha subunit with the beta-gamma dimer.

107. (C) Endoplasmic reticulum membrane
The perception of the ethylene hormone signal in plants occurs via a family of specific receptors. Unlike many other hormone receptors that are found in the nucleus or on the plasma membrane, ethylene receptors are primarily localized to the membrane of the endoplasmic reticulum. Upon binding ethylene, these receptors initiate a signaling cascade that leads to various physiological responses.

108. (C) The target mRNA coding sequence
The specificity of microRNA-mediated gene silencing in plants is remarkably high, relying on near-perfect base pairing with the target transcript. This interaction typically occurs within the coding sequence of the target messenger RNA, although it can also involve the untranslated regions. By binding to these specific sites, the microRNA guides the effector complex to initiate transcript cleavage or repression.

109. (B) RNAi allows viable knockdowns of genes that are otherwise lethal.
RNA interference is a valuable tool for functional validation experiments, offering several advantages over creating stable knockout lines. One significant benefit is that RNAi can achieve a partial reduction in gene expression, known as a knockdown. This allows researchers to study the function of genes that would be lethal if completely deleted, providing insights into essential biological processes.

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by a less condensed structure, which allows the transcriptional machinery and regulatory proteins to access the DNA. As a result, euchromatin is generally transcriptionally active. This contrasts with heterochromatin, which is highly condensed, densely stained, and typically contains silenced or repetitive DNA.

92. (B) An RNA intermediate
Class I transposable elements, also known as retrotransposons, are major contributors to genome expansion in many plant species. These elements utilize a copy-and-paste mechanism that involves an RNA intermediate. The element is first transcribed into RNA and then reverse-transcribed back into DNA by a specialized enzyme. The new copy is then integrated into a different location, increasing the size.

93. (A) The genome loses its characteristic four-part circular organization.
The characteristic four-part organization of the land plant chloroplast genome depends on the presence of two large inverted repeats. These repeats separate the large and small single-copy regions, providing structural stability. If a mutation deletes one of these repeats, the genome loses this specific configuration. This structural change can influence the frequency of recombination and the overall stability.

94. (D) Genomic rearrangement
Plant mitochondrial genomes exhibit an unusual evolutionary pattern characterized by slow rates of nucleotide sequence evolution but exceptionally high rates of genomic rearrangement. Frequent homologous recombination across large repeat sequences continually breaks and rejoins the DNA, leading to a multipartite structure. This high structural fluidity allows the genome to reorganize its gene order and composition rapidly despite few mutations.

95. (C) Introns
The open reading frames of many eukaryotic nuclear genes are interrupted by non-coding sequences known as introns. These regions are transcribed along with the exons but are subsequently removed from the pre-messenger RNA during the splicing process. The removal of introns and the precise ligation of exons are essential for producing a mature transcript that correctly encodes the intended protein.

96. (B) 5'-5' triphosphate linkage
During eukaryotic messenger RNA processing, a 7-methylguanosine cap is added to the 5' end of the transcript. This cap is connected to the nascent RNA via an unusual 5'-5' triphosphate linkage, which differs from the standard 3'-5' phosphodiester bonds found elsewhere. This unique structural feature protects the transcript from degradation by exonucleases and facilitates its recognition.

97. (A) The Mediator complex
The Mediator complex is a massive multiprotein assembly that plays a central role in eukaryotic transcriptional regulation. It functions as a molecular bridge, physically connecting distal transcriptional activators or repressors to the basal general transcription machinery and RNA polymerase II. By facilitating these interactions, the Mediator complex integrates regulatory signals and ensures the precise initiation of gene transcription.

98. (B) Constitutive promoter
A constitutive promoter is a regulatory sequence that drives gene expression uniformly across virtually all cell types and developmental stages within an organism. Unlike inducible or tissue-specific promoters, constitutive promoters are not restricted by environmental or developmental cues. Classic examples, such as the ubiquitin or actin promoters, are widely used in plant biotechnology to ensure high levels of transgene.

99. (A) Sigma factors
The plastid-encoded RNA polymerase is a multi-subunit enzyme structurally similar to bacterial polymerases. To achieve full transcriptional specificity and recognize particular promoter sequences, it requires additional nuclear-encoded proteins known as sigma factors. These factors bind to the core enzyme and guide it to the correct initiation sites. This interaction reflects the coordinated control between the nuclear and plastid.

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100. (A) P-4, Q-1, R-2, S-3
Plant hormone signaling frequently involves the degradation of specific repressor proteins to activate downstream responses. Auxin triggers the destruction of AUX/IAA proteins, while gibberellin leads to the degradation of DELLA repressors. Similarly, jasmonic acid signaling involves JAZ proteins, and brassinosteroid

the cap and the start codon. This region plays a critical role in regulating the initiation and efficiency of translation. It contains structural elements and sequences that facilitate the recruitment of ribosomes and initiation factors, thereby influencing the rate at which the protein is synthesized.

28. (C) U1 snRNP
Splicing of eukaryotic pre-messenger RNA is performed by the spliceosome, a complex composed of small nuclear ribonucleoproteins. The U1 snRNP specifically recognizes and binds to the 5' splice site at the beginning of an intron through base-pairing interactions. This initial recognition step is essential for the correct assembly of the spliceosome and the subsequent removal of the non-coding sequence.

29. (D) DNA sequence recognition and binding
Transcription factors are proteins that regulate gene expression by interacting with specific DNA sequences. They possess specialized structural domains, such as zinc fingers or leucine zippers, which are designed for sequence-specific recognition and binding. These domains allow the factor to dock securely into the major groove of the DNA double helix, facilitating the recruitment or inhibition of the machinery.

30. (B) I, III, IV and V
Specialized promoters are essential for controlling the spatial and temporal expression of genes in plants. Tissue-specific promoters utilize unique cis-regulatory motifs to confine expression to certain organs, such as roots or floral tissues. Synthetic promoters can be engineered by combining multiple cis-elements to achieve targeted expression patterns. These tools are invaluable for basic research and biotechnological applications in crops.

31. (B) Housekeeping genes and ribosomal proteins
Chloroplast transcription is managed by two distinct RNA polymerases with different roles. The nuclear-encoded polymerase is a single-subunit enzyme that is primarily active during early plastid development. It focuses on transcribing housekeeping genes and components of the plastid's own genetic machinery, such as ribosomal proteins. This ensures that the chloroplast can subsequently build the complex photosynthetic apparatus required for growth.

32. (D) Pentatricopeptide repeat (PPR) proteins
Nuclear restorer genes are essential for overcoming cytoplasmic male sterility by suppressing the effects of mitochondrial mutations. These genes predominantly encode members of the pentatricopeptide repeat protein family. PPR proteins are targeted to the mitochondria, where they bind to specific transcripts to facilitate their cleavage, degradation, or modification. This process prevents the accumulation of toxic proteins that disrupt pollen development.

33. (A) Nucleus and chloroplast
The Rubisco enzyme complex is composed of large subunits encoded by the chloroplast genome and small subunits encoded by the nuclear genome. The synthesis and assembly of these components require precise stoichiometric balance. This necessitates tight coordination through signaling pathways that communicate the status of the two compartments, ensuring that both types of subunits are produced in appropriate quantities.

34. (C) NodD
In the rhizobium-legume symbiosis, the initiation of nodulation is controlled by chemical signals between the plant and the bacteria. The plant secretes specific flavonoids that are perceived by the bacterial NodD protein. NodD acts as a transcription factor that, upon binding the flavonoid ligand, activates the expression of other nodulation genes. This leads to the production of Nod factors.

35. (A) Relaxation into transcriptionally active euchromatin
Histone acetyltransferases are enzymes that add acetyl groups to the lysine residues of histone tails. This modification neutralizes the positive charge of the histones, reducing their affinity for the negatively charged DNA. As a result, the chromatin structure relaxes into a more open state known as euchromatin. This transition increases the accessibility of the DNA for the transcription machinery.

36. (D) Knockout line validation
Determining the biological function of a gene is a core objective of functional genomics. One common approach involves creating knockout lines, where the specific gene is disabled or deleted. By comparing the resulting mutant phenotype with the wild-type organism, researchers can infer the gene's original role. This methodology

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110. (A) I and II
Simple Sequence Repeats consist of tandemly repeated core motifs, typically one to six base pairs in length. They are highly polymorphic molecular markers, primarily due to a phenomenon known as slipped-strand mispairing during DNA replication. This leads to variations in the number of repeat units between individuals. Their high abundance and stability make them indispensable for genetic mapping and diversity.

111. (B) Genome-Wide Association Studies (GWAS)
High-density genetic maps generated through SNP genotyping are essential prerequisites for genome-wide association studies. GWAS is a modern plant breeding methodology that seeks to identify statistical associations between specific genetic markers and phenotypic traits across diverse populations. By utilizing millions of SNPs, researchers can pinpoint genomic regions responsible for variations in complex traits with high precision and resolution.

112. (B) Acetyl groups
The organization of plant chromatin is dynamically regulated through various epigenetic modifications. Histone deacetylases are enzymes that catalyze the removal of acetyl groups from the tails of core histone proteins. This process restores the positive charge of the histones, increasing their affinity for the DNA and promoting chromatin condensation. As a result, the DNA becomes less accessible for transcription.

113. (B) Retrotransposons
Enormous variations in plant genome sizes, as seen in the Liliaceae family, are predominantly caused by the accumulation of repetitive DNA. Retrotransposons, which utilize a copy-and-paste mechanism involving an RNA intermediate, are particularly responsible for this expansion. By continually integrating new copies into the genome, these elements can massively increase total DNA content without significantly increasing the number.

114. (C) Specific subunits of the NADH dehydrogenase complex
The typical chloroplast genome features a conserved structure with large and small single-copy regions. The small single-copy region is notable for containing several genes essential for the organelle's function. In many land plants, this region includes genes encoding specific subunits of the NADH dehydrogenase complex, which participates in the chlororespiratory pathway and plays a role in maintaining redox balance.

115. (A) Mitochondria are predominantly transmitted through the egg cell.
Cytoplasmic male sterility is a maternally inherited trait because the mutations responsible for it reside in the mitochondrial genome. In most crop species, mitochondria are predominantly transmitted to the next generation through the egg cell, while the paternal contribution from pollen is minimal or absent. This uniparental inheritance pattern ensures that the CMS phenotype is predictably passed from mother.

116. (B) Alternative splicing
Alternative splicing is a fundamental biological process that allows a single nuclear gene sequence to produce multiple distinct mature messenger RNA isoforms. This occurs when different combinations of exons are selectively included or excluded from the final transcript. By generating diverse proteins from a single gene, alternative splicing significantly increases the functional complexity of the eukaryotic proteome.

117. (C) Messenger RNA (mRNA)
Eukaryotic cells utilize three distinct nuclear RNA polymerases for transcription. RNA polymerase II is explicitly responsible for synthesizing all messenger RNA molecules, which carry the genetic information for protein synthesis. Additionally, it transcribes most small nuclear RNAs and microRNAs. Its activity is tightly regulated by a diverse array of transcription factors and cis-regulatory elements to ensure precise gene.

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118. (D) Pleckstrin homology (PH) domain
Plant transcription factors utilize various structural motifs to recognize and bind to specific DNA sequences. Common DNA-binding domains include the basic leucine zipper, the Myb-like domain, and the WRKY domain, which are essential for regulating gene expression. The pleckstrin homology domain, however, is not typically a DNA-binding motif; instead, it is involved in protein-lipid interactions and membrane recruitment.

119. (A) RY repeats
Seed-specific promoters are essential for confining gene expression to maturation stages. These regulatory sequences often contain critical cis-regulatory motifs known as RY repeats. These elements are specifically recognized by B3 domain transcription factors, which play a central role in the regulation of seed maturation and the accumulation of storage proteins. Their presence ensures the targeted activation of genes.

120. (C) IV only
Chloroplast transcription involves two distinct RNA polymerases with different roles. The plastid-encoded polymerase is a multi-subunit enzyme that transcribes photosynthetic genes. The nuclear-encoded polymerase is a single-subunit enzyme that typically transcribes housekeeping genes during early development. The claim that the nuclear-encoded polymerase exclusively transcribes photosynthetic genes is incorrect, as this task is primarily performed by the plastid-encoded polymerase.

121. (A) Processing or degrading abnormal mitochondrial transcripts
Fertility restorer genes function by mitigating the deleterious effects of the mitochondrial mutations responsible for cytoplasmic male sterility. These genes typically encode proteins that act post-transcriptionally to target and modify or degrade the abnormal mitochondrial transcripts. By preventing the translation of these toxic proteins, the restorer genes ensure that normal pollen development can proceed, thereby restoring fertility to the.

122. (A) Retrograde signaling from plastid to nuclear rbcS transcription
The synthesis of the Rubisco holoenzyme requires precise coordination between the nuclear and chloroplast genomes to ensure stoichiometry. This is achieved through retrograde signaling, where signals from the plastid influence the transcription of the nuclear rbcS genes. This communication ensures that the production of small subunits in the cytoplasm matches the availability of large subunits synthesized within the organelle.

123. (B) Leghemoglobin
Root nodule symbiosis is characterized by the presence of leghemoglobin, a unique oxygen-binding protein. This protein is essential for protecting the oxygen-sensitive nitrogenase enzyme within the nodule. By reversibly binding to free oxygen, leghemoglobin maintains an extremely low oxygen tension while still ensuring a sufficient supply for the bacteria's high respiratory demands during the energetic process of nitrogen fixation.

124. (A) ATP hydrolysis
Chromatin remodeling complexes are essential for regulating gene expression by dynamically altering the position of nucleosomes along the DNA. This structural manipulation is an energy-demanding process that directly consumes energy derived from ATP hydrolysis. By sliding or repositioning nucleosomes, these complexes expose or hide specific DNA sequences, thereby controlling the accessibility of the genetic information for the transcriptional machinery.

125. (A) Gene targeting/knockout
Gene targeting is a powerful experimental technique used to confirm the functional identity of a newly cloned gene. This methodology relies on the introduction of specific mutations or the complete deletion of the gene via homologous recombination. By observing the resulting changes in the organism's phenotype, researchers can definitively determine the gene's biological role and validate its essential function.

126. (A) Measuring current disruptions without DNA polymerase synthesis
Oxford Nanopore technology represents a significant departure from other sequencing platforms by measuring current disruptions as single DNA molecules pass through protein pores. Unlike Illumina and PacBio, it does not rely on DNA polymerase-mediated synthesis or fluorescent labels. This unique approach allows for the generation of ultra-long reads and the direct detection of base modifications in real-time.

127. (B) Plasma membrane Na+/H+ antiporter
The SOS1 protein is a critical component of the Salt Overly Sensitive signaling pathway, which is essential for ion homeostasis in plants. Functionally, SOS1 operates as a Na+/H+ antiporter localized to the plasma membrane. It utilizes the proton gradient to actively export excess sodium ions from the cytoplasm into the extracellular space, thereby preventing sodium toxicity during stress.

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STAY ONE STEP AHEAD.

128. (A) MAPKKK → MAPKK → MAPK
Mitogen-Activated Protein Kinase cascades are central to transmitting extracellular signals into the nucleus in response to stress. These pathways follow a strict sequential order of phosphorylation events. The cascade begins with the activation of a MAPKKK, which phosphorylates a MAPKK. The MAPKK then phosphorylates a MAPK, which can then translocate into the nucleus to regulate the activity of factors.

129. (C) E3 (Ubiquitin ligase)
Ubiquitination is a multi-step process that marks regulatory proteins for degradation by the 26S proteasome. The specificity of this system is primarily determined by E3 ubiquitin ligases. These enzymes explicitly recognize and bind to the target protein, facilitating the transfer of ubiquitin molecules. By selecting which proteins are tagged, E3 ligases control numerous biological processes, including hormone signaling pathways.

130. (C) V only
Plant endogenous small RNAs, such as microRNAs and small interfering RNAs, are key regulators of gene expression. They function through mechanisms like transcript cleavage and DNA methylation, involving Dicer-like and Argonaute proteins. The statement that these small RNAs are primarily responsible for synthesizing entirely new proteins is incorrect, as their biological role is to regulate the activity of existing genes.

131. (B) Passenger strand
In the RNA interference pathway, the processing of double-stranded RNA results in a short duplex. During the assembly of the silencing complex, one strand is loaded to serve as the guide, while the other strand is excluded. This excluded strand is termed the passenger strand. It is typically degraded shortly after its release, ensuring that only the correct sequence is used.

132. (C) SNP
Single Nucleotide Polymorphism markers are based on variations at a single base position in the DNA sequence. They represent the most abundant source of genomic variation and can include base substitutions as well as small insertions or deletions. Due to their high frequency and stability, SNP markers offer exceptional resolution for genetic mapping, diversity analysis, and genome-wide association studies.

133. (A) Genotypic profiling at early developmental stages
Marker-assisted selection significantly accelerates the plant breeding cycle by allowing for selection based on genotypic profiling. Because molecular markers detect variations at the DNA level, they can be evaluated at early developmental stages, such as the seedling stage. This bypasses the need to wait for mature plant phenotypic manifestations, enabling breeders to make more rapid and accurate decisions.

134. (A) The flexible N-terminal tails of the core histones
The packaging of nucleosomes into the 30 nm chromatin fiber is a critical structural process in eukaryotic nuclei. This organization is facilitated by the flexible N-terminal tails of the core histones. These tails extend out from the nucleosome and interact with the DNA and histones of adjacent particles. These interactions are essential for stabilizing the condensed fiber and are subject to.

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135. (B) LTR (Long Terminal Repeat) retrotransposons
The maize genome is characterized by a high proportion of repetitive DNA, largely consisting of long terminal repeat retrotransposons. These transposable elements utilize a copy-and-paste mechanism involving an RNA intermediate to increase their copy number. In maize, LTR retrotransposons are overwhelmingly abundant and are often found in nested arrangements, significantly contributing to the overall expansion of the genome size.

136. (C) Oxidative phosphorylation
RNA editing in plant mitochondria is a post-transcriptional process that alters the nucleotide sequence of transcripts, often changing the encoded amino acids. This phenomenon is essential for the functional correction of genes involved in critical cellular processes, particularly oxidative phosphorylation. By ensuring the production of functional proteins for the electron transport chain, RNA editing is vital for energy production.

155. (A) C-to-U editing creating an AUG codon
RNA editing in plant mitochondria often alters transcripts to ensure the production of functional proteins. One common outcome is the introduction of functional start codons into transcripts that lack them. This is predominantly accomplished through C-to-U editing, which converts a non-start codon into an AUG start codon. This modification is essential for the correct initiation of translation for several mitochondrial genes.

156. (C) Splicing of eukaryotic pre-mRNA introns
The highly conserved GT-AG rule is a fundamental principle in eukaryotic molecular biology that defines the boundaries of introns. During the splicing of pre-messenger RNA, the intron typically begins with the dinucleotide GT at its 5' end and ends with the dinucleotide AG at its 3' end. These sequences are recognized by the spliceosomal machinery to ensure precise excision.

157. (A) The Kozak consensus sequence enclosing an AUG start codon
In eukaryotic messenger RNA, the exact start site for translation is defined by a specific sequence feature. The Kozak consensus sequence, which typically encloses an AUG start codon, serves as the recognition site for the ribosome. The surrounding nucleotides influence the efficiency of translation initiation. Proper identification of this site is essential for ensuring that the correct protein product is synthesized.

158. (C) The Mediator complex
Enhancer elements can loop over long physical distances to interact with the core promoter of a gene. This interaction is structurally stabilized by the Mediator complex, a massive multiprotein assembly that acts as a molecular bridge. By facilitating the contact between distal activators and the general transcription machinery, the Mediator complex ensures the precise and efficient initiation of gene transcription.

159. (A) CaMV 35S
For biotechnological applications requiring strong and continuous expression of a transgene, researchers often select a constitutive promoter. The 35S promoter from the Cauliflower Mosaic Virus is the most classically preferred promoter for this purpose in dicot plants. It drives high levels of expression across virtually all tissues and developmental stages, making it a powerful tool for overexpressing desirable traits in crops.

160. (A) COI1 binding → JAZ degradation → MYC2 activation → Target gene expression
The jasmonate signaling pathway follows a strict sequence of events to trigger plant responses to stress. It begins with the binding of jasmonate to the COI1 receptor, which is an E3 ubiquitin ligase. This interaction targets JAZ repressor proteins for degradation by the proteasome. The removal of these repressors allows MYC2 transcription factors to activate the expression of jasmonate-responsive target genes.

161. (B) The TIC and TOC translocon complexes
The assembly of the Rubisco holoenzyme requires the import of nuclear-encoded small subunits into the chloroplast. This targeted transit relies on the TIC and TOC translocon complexes, which are located in the inner and outer chloroplast membranes, respectively. These protein channels recognize the transit peptide on the incoming subunit and facilitate its passage into the stroma for assembly.

162. (B) Reversibly binding and buffering free oxygen in the nodule
Leghemoglobin is a unique protein essential for the success of biological nitrogen fixation in legume root nodules. It functions by reversibly binding to and buffering free oxygen within the nodule tissue. This creates a low-oxygen environment that prevents the irreversible inactivation of the nitrogenase enzyme while still providing enough oxygen to support the high respiratory activity of the symbiotic bacteria.

163. (B) Gametogenesis and early embryogenesis
DNA methylation is a key epigenetic mark that must be dynamically regulated during certain stages of the plant life cycle. Specifically, the processes of gametogenesis and early embryogenesis require extensive demethylation mechanisms to reset gene expression patterns. This resetting ensures that the offspring correctly establish the developmental programs necessary for growth, while also silencing transposable elements to maintain genomic integrity.

164. (A) Total RNA extraction followed by mRNA enrichment
The fundamental initial step in processing samples for RNA sequencing is the extraction

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146. (A) The G-alpha subunit
In standard G-protein signaling pathways, the G-alpha subunit acts as the primary molecular switch. It binds to guanine nucleotides and exists in an active or inactive state. Upon receptor activation, the alpha subunit binds GTP and dissociates from the beta-gamma dimer to interact with effectors. The signal is terminated when the alpha subunit hydrolyzes the GTP back into GDP.

147. (A) DELLA
Gibberellic acid promotes plant growth by initiating the degradation of specific repressor proteins known as DELLA proteins. When GA binds to its receptor, GID1, it undergoes a conformational change that allows it to interact with the DELLA proteins. This interaction targets the repressors for ubiquitination and subsequent degradation by the 26S proteasome, thereby releasing the inhibition of growth-promoting transcription factors.

148. (A) miRNAs originate from single-stranded hairpin precursors
Plant microRNAs and small interfering RNAs are distinguished primarily by their biogenesis pathways and the structure of their precursors. MicroRNAs originate from single-stranded primary transcripts that fold into characteristic hairpin structures, which are then processed by Dicer-like enzymes. In contrast, small interfering RNAs are derived from long, double-stranded RNA molecules. Both types of small RNAs function as key regulators.

149. (B) Phloem
The systemic spread of the RNA interference silencing signal allows for coordinated gene regulation throughout the plant. This mobile signal travels over long distances via the phloem, the plant's primary vascular tissue for transporting organic nutrients. By moving through the phloem, the silencing signal can reach distant tissues, ensuring that the entire organism responds to the initial trigger, such as.

150. (A) P-3, Q-4, R-1, S-2
Molecular marker types are defined by their unique functional characteristics and methods of detection. RAPD markers utilize arbitrary primers for dominant amplification, while RFLP markers detect co-dominant variations at restriction sites. SSR markers identify length variations in tandem repeats through PCR, and SNP markers represent single base variations. These diverse tools are essential for genetic mapping and diversity analysis in.

151. (A) Control by many minor-effect genes (QTLs)
The successful application of marker-assisted selection for complex quantitative traits is often limited by the genetic architecture of the trait. Such traits are typically controlled by many minor-effect genes or quantitative trait loci. Identifying and tracking all these loci simultaneously is challenging and requires extensive genomic data and advanced statistical models. This complexity makes MAS less straightforward than for single-gene traits.

152. (B) The nuclear lamina
The nuclear lamina is a structural network of proteins that lies beneath the inner nuclear membrane. It provides essential structural support to the nucleus and physically connects the chromatin to the nuclear envelope. By organizing the spatial arrangement of the genome, the nuclear lamina plays a critical role in maintaining nuclear integrity and regulating processes such as DNA replication and transcription.

153. (A) Proliferation of nested elements and genome expansion
The activity of long terminal repeat retrotransposons has a significant impact on plant genomic architecture. These elements utilize a copy-and-paste mechanism that leads to the proliferation of new copies across the genome. Over time, this results in the formation of nested elements and significant genome expansion. This process is a major driver of the variations in genome size observed across.

154. (C) Short Single Copy (SSC) and Large Single Copy (LSC)
The standard chloroplast genome features a highly conserved structure composed of four main parts. This includes two identical inverted repeats that separate the genome into two single-copy regions of different sizes. These are specifically referred to as the short single-copy and large single-copy regions. This unique arrangement is characteristic of the plastome in most land plant species and ensures stability.

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transposon is the presence of target site duplications. These are short, identical sequences generated during the integration process when the transposase enzyme cleaves the host DNA. TSDs serve as a permanent footprint of the transposition event and are used to.

174. (A) Class I Retrotransposons
Class I transposable elements, also known as retrotransposons, utilize a unique transposition cycle that requires a reverse transcriptase enzyme. These elements are first transcribed into an RNA intermediate, which then serves as a template for the enzyme to synthesize a new DNA copy. This copy is then integrated into a different genomic location, allowing the element to increase its total.

175. (A) Within the nuclear genome
While the chloroplast genome encodes core structural genes for the photosynthetic machinery, the vast majority of proteins required for chloroplast function are encoded within the nuclear genome. These proteins are synthesized on cytoplasmic ribosomes and subsequently imported into the organelle through specialized translocon complexes. This dual genetic origin necessitates tight coordination between the nucleus and the plastid to ensure.

176. (A) Codon modifications generating functional starts or stops
RNA editing in plant mitochondria is a critical process that alters transcripts to ensure they encode functional proteins. This phenomenon primarily involves codon modifications, such as the conversion of cytidine to uridine. These edits can generate functional start or stop codons, or alter internal amino acids to match conserved sequences. This corrective mechanism is essential for the proper expression of mitochondrial.

177. (B) Silencers
Regulatory sequences in a eukaryotic gene can either increase or decrease the level of transcription. Silencers are specific cis-regulatory elements that drastically reduce transcriptional activity when bound by repressor proteins. They can be located far from the target gene and operate by interfering with the assembly or function of the transcription machinery, providing a mechanism for precise down-regulation of gene.

178. (C) Splicing
Eukaryotic transcripts undergo an essential processing step where non-coding introns are excised and coding exons are precisely ligated together. This molecular process is strictly termed splicing and is performed by the spliceosome within the nucleus. Proper splicing is critical for producing a mature messenger RNA that correctly encodes the intended protein, as any errors can lead to non-functional protein products.

179. (A) Specific cis-regulatory nucleotide motifs in the promoter
Tissue-specific promoter function relies on the presence of unique trans-acting factors found only in the target tissue. The interaction between these factors and the promoter is determined by specific cis-regulatory nucleotide motifs. These motifs serve as the binding sites for the transcription factors, allowing for the precise spatial and temporal control of gene expression based on the available regulatory.

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180. (C) Plastid-Encoded Polymerase (PEP)
The plastid-encoded polymerase is a multi-subunit enzyme that requires auxiliary sigma factors to selectively identify and bind to its cognate promoter sequences. These sigma factors are encoded in the nucleus and provide the specificity necessary for the transcription of photosynthetic genes. This interaction reflects the coordinated control between the nuclear and plastid genetic compartments, ensuring that chloroplast development is properly.

181. (A) The tapetum layer of the anther
Cytoplasmic male sterility is a maternally inherited trait that results in the failure of pollen development. The expression of the mitochondrial mutations responsible for CMS predominantly triggers premature cellular death in the tapetum layer of the anther. Because the tapetum is essential for providing nutrients and components for pollen wall formation, its disruption leads to the abortion of developing microspores.

182. (A) Rubisco holoenzyme
The TIC translocon complex is essential for importing nuclear-encoded proteins across the inner chloroplast membrane. A mutation that abolishes its function would have a catastrophic effect on the assembly of the Rubisco holoenzyme.

of total RNA from the target tissue. To focus the analysis on protein-coding sequences, this is typically followed by a step to enrich for messenger RNA. This can be achieved through poly-A selection or by depleting the abundant ribosomal RNA, ensuring that the resulting library represents.

165. (A) It allows visualization of single fluorescent nucleotide events
PacBio sequencing utilizes an immobilized DNA polymerase within a Zero-Mode Waveguide to achieve single-molecule sequencing. The ZMW provides a significant advantage by creating an extremely small detection volume that allows for the visualization of single fluorescent nucleotide incorporation events in real-time. This high sensitivity enables the platform to read long fragments of DNA directly without the need for prior amplification.

166. (A) Assist in the correct refolding of denatured proteins
Under high-temperature stress, cellular proteins are prone to unfolding and aggregation, which can be lethal. The induction of heat shock proteins primarily serves to protect the cell by acting as molecular chaperones. These proteins assist in the correct refolding of denatured molecules and prevent irreversible aggregation. This protective mechanism is vital for maintaining cellular homeostasis and ensuring survival during heat.

167. (C) The nucleus
Phytohormone receptors exhibit diverse subcellular localizations that are critical for their function. The well-characterized auxin receptor, TIR1, is predominantly localized within the nucleus. Upon binding auxin, TIR1 acts as a component of an E3 ubiquitin ligase complex to facilitate the degradation of transcriptional repressors. This nuclear localization ensures that the hormonal signal is directly linked to the regulation of.

168. (B) 26S proteasome
In plant signaling pathways, the targeted degradation of regulatory proteins is a common mechanism for controlling responses. This process requires the tagging of the protein with multiple ubiquitin molecules. The resulting polyubiquitin chain is specifically recognized by the 26S proteasome, a massive protein complex that functions as the cell's primary degradation machinery. The proteasome then breaks down the target.

169. (B) Transcriptional gene silencing via chromatin modifications
Plant small interfering RNAs often participate in the RNA-directed DNA methylation pathway. The ultimate functional outcome of this process is transcriptional gene silencing through the induction of chromatin modifications. By guiding methyltransferase enzymes to specific genomic locations, the siRNAs facilitate the addition of methyl groups to DNA and the modification of histones, leading to a highly condensed and inactive.

170. (A) II, IV, I, III
Eukaryotic chromatin is organized into multiple structural levels that increase in condensation. The sequence begins with the naked double-stranded DNA helix. This is then wrapped around histones to form the nucleosome core particles, often described as "beads on a string." These particles are further coiled into the 30-nm chromatin fiber, which ultimately condenses into the metaphase chromosome during cell.

171. (A) Polymerase Chain Reaction (PCR) and fragment analysis
Simple Sequence Repeat markers are highly multiallelic and reproducible, making them a standard tool for genetic analysis. They are assayed experimentally primarily through the use of polymerase chain reaction and fragment analysis. Specific primers flanking the repeat region are used to amplify the locus, and the resulting fragments are separated by size using electrophoresis to reveal length polymorphisms.

172. (D) Recovery of the recurrent parent genome
The success of marker-assisted backcrossing relies on selecting for two distinct sets of markers. While foreground selection targets the desirable trait from the donor parent, background selection is used to accelerate the recovery of the recurrent parent's genome. By selecting individuals that possess the target trait and the highest proportion of recurrent parent markers, breeders can rapidly restore the background.

173. (A) Target site duplications (TSDs)
Transposable elements can structurally alter the genome upon integration. A reliable sequence hallmark that flanks a newly integrated DNA

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it is derived from long double-stranded RNA molecules from various.

192. (A) Dominant marker
Amplified Fragment Length Polymorphism is a reliable and highly reproducible molecular marker technique. However, a significant inherent limitation of standard AFLP is that it typically acts as a dominant marker. This means that it cannot distinguish between homozygous dominant and heterozygous individuals at a specific locus. This characteristic must be considered when using AFLP for genetic mapping and diversity analysis.

193. (A) High abundance and uniform genomic distribution
Single Nucleotide Polymorphisms are robustly utilized in genome-wide association studies due to their high abundance and uniform distribution across the genome. SNPs represent variations at a single base position and are the most common source of genetic diversity. Their high frequency and stability allow researchers to achieve exceptionally high genomic resolution, making them ideal for identifying the loci responsible for traits.

194. (A) Telomeric repeats
Eukaryotic chromosomes are protected at their physical ends by telomeres, which are composed of repetitive DNA sequences. In plants, these telomeric repeats are commonly clustered in massive tandem arrays. They serve to protect the ends of the linear chromosomes from degradation and fusion, and are essential for maintaining genomic stability during successive rounds of cell division.

195. (A) Non-autonomous DNA transposons
Miniature inverted-repeat transposable elements are small, abundant repetitive elements found in many plant genomes. They are structurally classified as non-autonomous DNA transposons because they lack the genes necessary for their own transposition. Instead, MITEs rely on the transposase enzymes provided by related autonomous elements to move throughout the genome, where they can significantly impact gene expression and diversity.

196. (A) Two
The chloroplast genome typically contains two identical inverted repeat regions that are opposite in orientation. This structural feature ensures that any gene located within these repeats exists in two copies per circular plastome. This duplicated arrangement contributes to the high levels of production for essential components, such as ribosomal RNAs, and is a hallmark of the chloroplast's genetic organization.

197. (A) Oxidative phosphorylation
Although plant mitochondrial genomes are multipartite and complex, they fundamentally encode proteins that are primarily required for oxidative phosphorylation. These genes code for essential components of the electron transport chain and the ATP synthase complex. By ensuring the production of these proteins within the organelle, the mitochondrial genome supports the energetic demands of the cell through efficient energy production.

198. (A) Transcript stability and subcellular localization
The 3' untranslated region of a eukaryotic messenger RNA plays a critical role in post-transcriptional regulation. This region contains various structural elements and sequences that influence transcript stability and subcellular localization. By interacting with specific proteins and small RNAs, the 3' UTR determines the lifespan of the transcript and ensures that it is transported to the appropriate cellular compartment.

199. (A) Addition of a multi-adenine tract by poly-A polymerase
Polyadenylation is a key processing step that occurs at the 3' end of eukaryotic pre-messenger RNA. This process begins with the cleavage of the nascent transcript downstream of a conserved consensus sequence. This cleavage is closely coupled with the addition of a long tract of adenine residues by poly-A polymerase. This tail is essential for transcript stability and translation.

200. (A) P-2, Q-3, R-4, S-1
Successful gene expression requires the coordinated action of several essential transcription components. The TATA-binding protein recognizes the core promoter to recruit RNA polymerase, while trans-acting activators bind to distal cis-regulatory DNA sequences known as enhancers to upregulate expression. Finally, the spliceosome complex is responsible

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This is because the small subunits of Rubisco are synthesized in the cytoplasm and must be imported into the chloroplast stroma to associate with the large subunits.

183. (A) Flavonoid
In the rhizobium-legume symbiosis, the initiation of the relationship depends on complex chemical signaling. The initial host-derived signal molecule is typically a flavonoid secreted by the plant roots into the soil. These compounds are specifically perceived by the bacterial NodD protein, which then activates the expression of nodulation genes, leading to the production of Nod factors that initiate nodule.

184. (A) Promoter regions for transcription factor binding
Chromatin remodeling complexes utilize energy to reposition or slide nucleosomes along the DNA. This structural manipulation fundamentally alters the accessibility of the genetic material, particularly the promoter regions. By moving nucleosomes away from these sites, the complexes allow transcription factors and the transcriptional machinery to bind to the DNA, thereby facilitating the initiation of gene expression in response to various.

185. (A) Starting with a known gene sequence to deduce function
Forward and reverse genetics represent two complementary approaches to studying gene function. While forward genetics begins with a mutant phenotype and seeks to identify the causative gene, reverse genetics fundamentally relies on starting with a known gene sequence. Researchers use various techniques to disable or modify the gene and then observe the resulting phenotypic changes to deduce its biological role.

186. (A) The average representation of a base in the raw dataset
In high-throughput sequencing, the concept of sequencing depth or coverage refers to the average number of times each base in the genome is represented in the raw dataset. Higher depth provides greater confidence in the accuracy of the sequence and allows for the detection of rare variants. This metric is essential for ensuring that the data is sufficient for downstream.

187. (A) Calcium
The Salt Overly Sensitive pathway is a critical ion homeostasis network that allows plants to tolerate salinity stress. The activation of the primary sensor in this pathway, SOS3, relies strictly on the binding of calcium ions. Upon binding calcium, SOS3 undergoes a conformational change that allows it to interact with and activate the SOS2 kinase, initiating the downstream signaling cascade.

188. (A) Heterotrimeric G-protein
Secondary messengers are small molecules that relay signals from cell surface receptors to target molecules inside the cell. Common examples include calcium ions, cyclic AMP, and inositol trisphosphate. Heterotrimeric G-proteins, however, are not typically classified as secondary messengers. Instead, they function as membrane-associated molecular switches that bridge the gap between the receptor and the enzymes that produce secondary messengers.

189. (A) Potassium
Abscisic acid is a key hormone that regulates stomatal closure during water deficit. ABA-induced closure relies on the efflux of osmotically active ions, primarily potassium, from the guard cells. This loss of ions leads to a decrease in turgor pressure, causing the cells to shrink and the stomatal pore to close. This rapid response is essential for reducing transpiration and.

190. (A) Both A and R are true and R is the correct explanation of A.
Plant microRNAs generally regulate gene expression by directing the cleavage of their target messenger RNA molecules. This process requires near-perfect complementarity between the microRNA and its target transcript. The microRNA guides the Argonaute protein within the silencing complex to the specific site for endonucleolytic slicing. This mechanism allows for the precise down-regulation of target genes during development and stress.

191. (A) A double-stranded RNA region
Dicer-like enzymes are central components of the small RNA biogenesis pathways in plants. These enzymes require a double-stranded RNA region in their substrate to recognize and process it into functional small RNAs. For microRNAs, this structure is provided by the hairpin of the primary transcript. For small interfering RNAs,

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137. (A) Prokaryotic mRNAs are frequently polycistronic; eukaryotic are monocistronic.
There are fundamental functional differences between prokaryotic and eukaryotic messenger RNA transcripts. Prokaryotic mRNAs are frequently polycistronic, meaning a single transcript encodes multiple different proteins. In contrast, eukaryotic mRNAs are typically monocistronic, carrying the information for only one protein. Additionally, eukaryotic transcripts undergo extensive processing, including capping and polyadenylation, within the nucleus before they are transported for translation.

138. (B) It functions reliably regardless of upstream or downstream orientation.
Enhancers possess unique functional properties that distinguish them from core promoter regions. A definitive characteristic of an enhancer is its ability to operate reliably regardless of its physical orientation or its distance from the transcription start site. They can be located thousands of base pairs upstream or downstream of a gene and function by providing binding sites for transcriptional activators.

139. (A) Transforming a plant with the promoter fused to a reporter gene
To provide definitive experimental proof that a selected DNA sequence functions as a tissue-specific promoter, researchers typically utilize reporter gene assays. By fusing the promoter to a reporter gene, such as GUS, and transforming it into a plant, the resulting expression pattern can be visualized. This allows for the precise determination of where and when the promoter is active.

140. (A) Both A and R are true and R is the correct explanation of A.
Plant mitochondrial genomes possess a complex multipartite structure instead of a single stable circle. This organization is driven by high-frequency homologous recombination mediated by large repeated sequences. These recombination events continually break and rejoin the master circle into smaller subgenomic molecules. This structural fluidity is a defining hallmark of plant mitochondria, resulting in a population of coexisting DNA molecules.

141. (B) An N-terminal transit peptide
The coordinate expression of photosynthesis genes requires many nuclear-encoded proteins to be imported into the chloroplast. This targeted import is mediated by an N-terminal transit peptide present on the newly synthesized protein. This specialized sequence is recognized by translocon complexes in the chloroplast membranes, which facilitate the protein's entry. Once inside, the transit peptide is typically removed by a protease.

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142. (B) Infection thread
In the rhizobium-legume symbiosis, the bacteria enter the host plant's root through a specialized structural adaptation known as an infection thread. This tubular structure is derived from the plant cell membrane and wall, extending from the root hair into the cortex. It provides a protected pathway for the bacteria to reach the developing nodule cells where they will eventually fix.

143. (A) Chromatin Immunoprecipitation followed by sequencing (ChIP-seq)
Chromatin immunoprecipitation followed by sequencing is a powerful technique used to determine the genome-wide binding sites of specific transcription factors in vivo. This process involves cross-linking proteins to DNA, fragmenting the chromatin, and using specific antibodies to isolate the target protein and its associated DNA. Subsequent sequencing of these fragments reveals the exact locations where the factor interacts with the.

144. (B) Read mapping (Reference-based assembly)
High-throughput sequencing generates millions of short reads that must be computationally organized to reveal the genetic code. The process of aligning these reads to an existing completed reference genome is known as read mapping or reference-based assembly. This approach allows researchers to identify variations, such as SNPs, and determine the presence of specific sequences within the newly sequenced sample.

145. (A) CBF/DREB1
Cold acclimation and freezing tolerance in plants are coordinated by a specific family of transcription factors known as CBF or DREB1. These factors are rapidly induced by low temperatures and bind to conserved elements in the promoters of cold-responsive genes. By activating a broad range of protective proteins, they enhance the plant's ability to survive and adapt to freezing.

for removing non-coding introns from the pre-messenger RNA. These elements ensure correct mRNA production.

201. (A) Toxicity to non-target soil organisms exposed to roots
Tissue-specific expression constructs are valuable tools for crop improvement and biotechnology. For example, driving an insecticidal protein gene with a leaf-specific promoter allows the protein to be expressed where pests feed. This targeted strategy primarily avoids potential toxicity to non-target soil organisms that would otherwise be exposed if the protein were produced in the roots or throughout the plant.

202. (A) Early plastid development (proplastid stage)
Chloroplast transcription is managed by two distinct RNA polymerases that act at different developmental stages. The nuclear-encoded polymerase is targeted to the chloroplast to transcribe genes that are critical during early plastid development, such as components of the genetic machinery. This activity ensures that the organelle is prepared for the subsequent maturation into a photosynthetic chloroplast driven by the plastid-encoded polymerase.

203. (A) Mitochondrial RNA editing or cleavage
Nuclear restorer genes function post-transcriptionally to neutralize the effects of mitochondrial mutations responsible for cytoplasmic male sterility. These genes frequently encode members of the pentatricopeptide repeat protein family. PPR proteins are targeted to the mitochondria, where they bind to specific transcripts to facilitate RNA editing or cleavage. By preventing the accumulation of toxic proteins, they ensure normal pollen development.

204. (A) The large subunit encoded by the plastome
The Rubisco enzyme complex is composed of large and small subunits that have different origins and functions. The large subunit, which is encoded by the plastid genome, uniquely acts as the catalytic core of the enzyme. It is at this site that carbon dioxide is fixed to ribulose-1,5-bisphosphate during the Calvin cycle. The small subunits contribute to enzyme stability.

205. (A) FixL / FixJ
In biological nitrogen fixation, the expression of genes encoding the structural components of nitrogenase is tightly regulated in response to oxygen levels. This is achieved through a specific two-component regulatory system known as FixL/FixJ. The FixL protein acts as an oxygen sensor, while FixJ is the response regulator that activates the transcription of nif and fix genes under low-oxygen.

206. (A) H3K4
Histone methylation is a critical epigenetic mark that can correlate with either transcriptional activation or repression depending on the specific residue modified. Generally, the trimethylation of histone H3 at the lysine 4 position is considered a universal mark of active euchromatin. This modification is typically found at the promoter regions of genes that are being actively transcribed by the.

207. (A) Functional genomics via targeted knockout
Creating a deletion of an endogenous gene to observe the resulting mutant phenotype is a fundamental approach in functional genomics. This targeted knockout strategy allows researchers to determine the consequences of disabling a specific gene, thereby inferring its biological role. By comparing the mutant with the wild-type organism, the essential functions and interactions of the gene can be definitively characterized.

208. (A) Capacity to generate ultra-long continuous reads
Oxford Nanopore technology offers a significant advantage in resolving complex repetitive regions and assembling large genomes. This advantage is derived from its capacity to generate ultra-long continuous reads that can span several kilobases. By providing long-range sequence information, these reads allow researchers to navigate through repetitive elements that often cause fragmentation in datasets generated by short-read sequencing platforms.

209. (A) Molecular shields protecting structures from desiccation
Late Embryogenesis Abundant proteins are highly hydrophilic molecules that play a pivotal role in plant drought tolerance. Functionally, LEA proteins act as molecular shields that protect cellular structures and proteins from the damaging effects of desiccation. By preventing denaturation and aggregation, these proteins maintain cellular integrity during severe water

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245. (A) Across virtually all tissues and developmental stages
Driving a transgene with a constitutive promoter ensures that the gene is transcribed continuously across virtually all tissues and developmental stages of the plant. Unlike inducible or tissue-specific promoters, constitutive promoters are not restricted by environmental or developmental cues. This approach is widely used in plant biotechnology when high and steady levels of a particular protein product are required throughout.

246. (A) E. coli bacterial RNA Polymerase
The plastid-encoded polymerase in chloroplasts is a multi-subunit enzyme that reflects the endosymbiotic bacterial origin of the organelle. It is structurally and functionally homologous to the RNA polymerase found in E. coli. This similarity includes the recognition of bacterial-like promoter elements and the requirement for sigma factors for transcriptional specificity. PEP is responsible for transcribing genes essential for the photosynthetic.

247. (A) Nucleus and Mitochondria
The genetic restoration of fertility in cytoplasmic male sterility systems demonstrates complex cross-talk between the nuclear and mitochondrial genomes. CMS is caused by mitochondrial mutations, while the restorer genes are located in the nucleus. These Rf genes encode proteins that are targeted to the mitochondria to modify or degrade the toxic transcripts. This coordination is essential for restoring normal pollen development.

248. (A) In the nuclear genome
The synthesis of the Rubisco holoenzyme requires coordination between different cellular compartments. While the large subunit is encoded by the rbcL gene in the chloroplast genome, the small subunit is encoded by the rbcS gene family in the nuclear genome. The small subunit transcripts are translated in the cytoplasm and the resulting proteins are imported into the chloroplast for assembly.

249. (A) In the plant cytoplasm of infected nodule cells
Symbiotic biological nitrogen fixation requires an extremely low oxygen tension to protect the nitrogenase enzyme. Leghemoglobin acts as an essential oxygen buffer in this process, localized within the plant cytoplasm of infected nodule cells. By reversibly binding to free oxygen, leghemoglobin ensures that oxygen levels are maintained at a level that supports bacterial respiration without inactivating the sensitive nitrogenase.

250. (A) P-4, Q-2, R-3, S-1
Epigenetic regulatory mechanisms are essential for controlling gene expression patterns in plants. DNA hypermethylation at promoters generally represses transcription initiation, while histone H3K4 trimethylation is a mark of highly active euchromatin. Histone deacetylation promotes tight chromatin condensation to silence genes, and chromatin remodeling complexes like SWI/SNF use energy for the repositioning of nucleosomes to alter DNA accessibility for factors.

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251. (A) Dynamic expression levels of mRNA transcripts
Utilizing transcriptomics allows a researcher to survey the dynamic expression levels of thousands of mRNA transcripts simultaneously within a cell. This approach provides a comprehensive view of how gene activity changes in response to developmental cues or environmental stimuli. By quantifying transcript abundance, transcriptomics offers valuable insights into the regulatory networks and biological processes that govern cellular function and adaptation.

252. (A) Indel errors around homopolymeric stretches
The Oxford Nanopore platform is a powerful tool for genomic sequencing but features a distinct error profile compared to other technologies. The dominant type of error observed in Nanopore reads consists of insertions and deletions, particularly around homopolymeric stretches of the same nucleotide. These errors occur when the electrical signal lacks sufficient resolution to accurately determine the exact number of repeated.

253. (A) SOS1 plasma membrane Na+/H+ antiporter
The Salt Overly Sensitive pathway is a hierarchical signaling network that regulates ion homeostasis during salinity stress. The pathway begins with the calcium-dependent activation of the SOS2 kinase. The final target of the activated SOS2 is the SOS1 protein, which functions as a Na+/H+ antiporter localized to the plasma membrane.

the circular DNA molecule. These processes are essential for maintaining the high copy number of the plastome within each organelle, ensuring that sufficient genetic information is available.

219. (A) Promiscuous DNA
Plant mitochondrial genomes are characterized by their ability to incorporate foreign genetic material through horizontal and intracellular gene transfer. These integrated segments, which can be derived from the chloroplast or nuclear genomes, are termed promiscuous DNA. This phenomenon contributes to the complexity and size of the mitochondrial genome and can sometimes lead to the acquisition of novel functional genes.

220. (B) I, III and IV
The fine structure of eukaryotic nuclear genes includes several essential functional elements. Introns must be completely removed from the pre-messenger RNA during splicing for correct protein synthesis. The promoter strictly dictates the basal level of transcription, while enhancers can drastically increase the rate of expression. The 5' untranslated region also plays a critical regulatory role in translation initiation and efficiency.

221. (A) A 7-methylguanosine via 5'-5' triphosphate bridge
The 5' cap of a mature eukaryotic messenger RNA is a fundamental modification that occurs shortly after transcription initiation. This structure consists of a 7-methylguanosine residue connected to the transcript via a unique 5'-5' triphosphate bridge. This cap is essential for protecting the transcript from exonuclease degradation and facilitates its recognition by the translational machinery and nuclear export proteins.

222. (A) Is a diffusible molecule encoded anywhere
In gene regulation, a fundamental distinction is made between cis-acting and trans-acting elements. A trans-acting factor is a diffusible molecule, typically a protein or RNA, that is encoded elsewhere in the genome. It can travel to its target gene to modulate expression. In contrast, a cis-acting element is a DNA sequence that must be physically located on the same.

223. (A) The Glutelin (Gt1) promoter
Endosperm-specific promoters are highly desirable for biotechnological applications aimed at improving the nutritional quality of seeds. The Glutelin promoter is a well-known example that drives strictly endosperm-specific expression in cereal crops like rice. By using this promoter to control a transgene, researchers can ensure that the desired protein is produced exclusively within the seed's storage tissue during maturation.

224. (A) Sequential action of early NEP followed by late PEP
Chloroplast biogenesis is a complex process driven by the sequential action of two different RNA polymerases. Early in development, the nuclear-encoded polymerase is primarily active, transcribing genes for the plastid's genetic machinery. As the organelle matures, the plastid-encoded polymerase becomes dominant, transcribing the genes necessary for the photosynthetic apparatus. This transition is essential for the transition from proplastid to.

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225. (A) Chimeric, novel open reading frames
Cytoplasmic male sterility is caused by mitochondrial mutations that interfere with normal pollen development. These CMS-associated genes are typically classified as chimeric, novel open reading frames that have arisen through genomic rearrangements. The protein products of these genes often localize to the mitochondrial membrane and disrupt energy production or other essential functions, leading to the failure of microspore maturation.

226. (A) Prevent aggregation and facilitate correct folding
The assembly of the Rubisco holoenzyme is a demanding process that requires the assistance of molecular chaperonins within the chloroplast stroma. These specialized proteins function to prevent the aggregation of the newly synthesized subunits and facilitate their correct folding. This assistance is essential for ensuring that the large and small subunits assemble into the functional hexadecameric complex required for.

227. (A) Host plant-derived photosynthates
Symbiotic nitrogen fixation in legume root nodules is an energetically expensive process that requires a massive input of ATP. This energy is supplied by host plant-derived photosynthates, primarily in the form of dicarboxylic acids like

mass in the second dimension. By organizing proteins into a 2D map, researchers can identify and quantify changes in the cellular proteome.

280. (A) BLAST
BLAST is the most commonly used bioinformatics tool for comparing a primary DNA or protein sequence against a vast database. It allows researchers to identify regions of similarity that may indicate evolutionary relationships or shared biological functions. By performing sequence alignment, BLAST helps to characterize unknown sequences based on their homology to well-studied genes or proteins, providing essential information for genomics.

281. (A) Provide high-density saturated coverage for precise QTL mapping
In quantitative genetics, the primary advantage of utilizing genome-wide SNP arrays is their ability to provide high-density saturated coverage of the genome. This resolution is essential for precise QTL mapping and genome-wide association studies. By identifying millions of single-base variations, SNP arrays allow researchers to pinpoint the genomic regions responsible for complex traits with exceptional accuracy and statistical power in breeding.

282. (A) Long GC-rich tandemly repeated sequences
The structural integrity of eukaryotic chromosomes is protected at their ends by specialized structures known as telomeres. In plants, telomeric DNA sequences are characterized by long, tandemly repeated sequences that are often GC-rich. These repeats prevent the loss of genetic information during DNA replication and protect the chromosomal ends from fusion or degradation, thereby maintaining genomic stability across many cell divisions.

283. (A) The highly conserved Polyadenylation signal sequence
During the transcription of a eukaryotic nuclear gene, a specific sequence feature signals the end of the transcript. The highly conserved polyadenylation signal sequence, typically AAUAAA, is recognized by the cleavage and polyadenylation machinery. This recognition leads to the cleavage of the nascent pre-messenger RNA and the subsequent addition of a poly-A tail, marking the successful completion of the transcription.

284. (A) DREB (Dehydration Responsive Element Binding)
The Dehydration Responsive Element Binding transcription factor family is intimately involved in regulating the plant's response to extreme dehydration. These factors are induced by water deficit and bind to specific cis-elements in the promoters of stress-responsive genes. By activating a broad range of protective proteins and pathways, DREB transcription factors enhance the plant's ability to survive and recover from stress.

285. (A) Cyclins
The progression of the eukaryotic cell cycle is a highly regulated process that depends on the periodic synthesis and degradation of specific proteins known as cyclins. These proteins bind to and activate cyclin-dependent kinases to drive the cell through different phases. The timely destruction of cyclins by the proteasome ensures that the cell cycle proceeds in a unidirectional and controlled manner.

286. (A) Red and far-red light
Phytochromes are a major class of plant photoreceptors that primarily perceive and respond to red and far-red light wavelengths. These receptors can switch between two interconvertible forms, allowing the plant to monitor the quality and duration of light in its environment. This information is used to regulate a wide range of developmental processes, including seed germination and flowering time.

287. (A) Imperfectly base-paired stem-loop hairpins
The biogenesis of microRNAs begins with primary transcripts that are processed by Dicer-like enzymes. These enzymes recognize a specific structural feature of the transcript, which consists of an imperfectly base-paired stem-loop hairpin. This hairpin structure provides the substrate for the enzyme to cleave the RNA into a mature microRNA duplex, which then functions as a guide for silencing complementary targets.

288. (A) Synteny
The conservation of gene order and orientation between the genomes of two different species is defined as synteny. This phenomenon reflects the evolutionary relationships between organisms and is used to identify homologous genomic regions. Synteny analysis is a powerful tool in comparative genomics, allowing researchers to

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using short, arbitrary primers to generate genomic profiles. This approach does not require prior sequence information and is used to identify genetic variations between individuals. The resulting banding patterns are used for diversity analysis and genetic.

237. (A) Scored with difficulty due to environmental variation
Marker-assisted selection offers significant advantages over conventional phenotypic selection, particularly for complex traits. It is especially effective for traits that are scored with difficulty due to high levels of environmental variation. By selecting individuals based on their molecular marker profiles, which are independent of the environment, breeders can make more accurate decisions at early developmental stages, accelerating the progress.

238. (A) Hypoacetylation and H3K9 methylation
Histone tails are subject to various post-translational modifications that regulate chromatin structure and gene expression. The combination of hypoacetylation and histone H3 lysine 9 methylation is generally regarded as the hallmark of silenced heterochromatin. These modifications recruit specific proteins that promote the condensation of the chromatin fiber, making the DNA inaccessible to the transcription machinery and effectively silencing associated genes.

239. (A) LTR Retrotransposons
The massive variations in genome size observed across different angiosperm families are predominantly explained by the accumulation of repetitive DNA. In many plants, expansions in the copy number of LTR retrotransposons are the primary drivers of this phenomenon. These elements utilize a copy-and-paste mechanism that leads to significant genome expansion over evolutionary time, contributing to the diversity of genomic.

240. (A) Both A and R are true and R is the correct explanation of A.
The chloroplast genome maintains stable structural configurations compared to the mitochondrial genome in most land plants. This stability is largely due to the presence of two large identical inverted repeats that are separated by single-copy regions. These repeats stabilize the circular structural integrity of the plastome and facilitate high-frequency intramolecular recombination, which helps maintain sequence homogeneity and structural consistency within.

241. (A) A population of subgenomic structural circles
Plant mitochondrial genomes are remarkably complex and exist in a dynamic structural state. High-frequency homologous recombination across large repeated sequences continually breaks and rejoins the DNA, leading to the generation of a population of subgenomic structural circles. This multipartite organization allows the mitochondrial genome to reorganize its gene order and composition rapidly, which is a defining hallmark of plant mitochondria.

242. (A) Between -25 and -30 base pairs
The TATA box is a fundamental cis-regulatory element that dictates the precise location where eukaryotic nuclear transcription initiates. This highly conserved sequence typically resides between 25 and 30 base pairs upstream of the transcription start site. It provides the specific binding site for the TATA-binding protein, which is the initial step in the assembly of the transcription pre-initiation complex.

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243. (A) Small nuclear RNAs (snRNAs)
Pre-messenger RNA splicing is a critical process in eukaryotic gene expression, performed by a ribonucleoprotein complex called the spliceosome. The catalytic core of this complex consists of small nuclear RNAs, which are responsible for recognizing splice sites and facilitating the chemical reactions necessary to excise introns and ligate exons. These snRNAs ensure the precise removal of non-coding sequences from the.

244. (A) Cis-regulatory elements in enhancers or promoters
Tissue-specific gene expression is driven by the interaction between distinct combinatorial arrays of transcription factors and their target sequences. these factors recognize and bind to specific cis-regulatory elements located within enhancers or promoter regions. by binding to these motifs, the transcription factors can activate or repress the expression of genes in a spatial and temporal manner across different plant tissues.

malate. These carbon compounds are transported into the nodules and metabolized by the bacteria through oxidative phosphorylation to generate the ATP necessary for nitrogenase.

228. (A) Methyl-CpG-binding domain (MBD) proteins
DNA methylation is a major epigenetic modification that alters chromatin structure and leads to gene silencing. This process generally recruits specialized proteins known as methyl-CpG-binding domain proteins. These proteins recognize and bind to methylated DNA, where they interact with other complexes, such as histone deacetylases, to promote the formation of condensed and transcriptionally inactive heterochromatin, thereby enforcing gene.

229. (A) Determine consequences of disabling a specific gene
T-DNA insertional mutagenesis is a powerful tool for functional genomics that allows researchers to create libraries of mutant plants. The purpose of analyzing a T-DNA knockout line is to determine the consequences of disabling a specific gene. By observing the resulting changes in the plant's phenotype, researchers can gain valuable insights into the biological role and function of the gene.

230. (A) I, III and IV
Illumina sequencing chemistry relies on the principle of sequencing by synthesis on a solid surface. This technology utilizes fluorescently labeled reversible terminators that are incorporated into a growing DNA strand. To achieve a detectable signal, bridge amplification is used to create clonal clusters of identical fragments on the flow cell. These features allow for the simultaneous sequencing of millions of.

231. (A) Binding DRE/CRT elements to upregulate COR genes
The primary function of DREB1/CBF transcription factors during cold stress acclimation is to regulate the plant's protective response. These factors bind to specific cis-elements known as DRE or CRT elements in the promoters of cold-responsive genes. This binding triggers the upregulation of COR genes, which encode proteins that stabilize membranes and protect cellular structures from damage caused by low.

232. (A) Exchange of GDP for GTP on the G-alpha subunit
G-protein-coupled receptors transmit extracellular signals into the cell through a specific structural change upon ligand binding. This change promotes the exchange of GDP for GTP on the associated G-alpha subunit. The binding of GTP activates the alpha subunit, causing it to dissociate from the beta-gamma dimer and interact with various downstream effectors to initiate a signaling cascade within the cell.

233. (A) Negative repressors of growth-promoting genes
The gibberellin signaling pathway is essential for plant growth and development, acting through the degradation of DELLA proteins. These proteins functionally operate as negative repressors of growth-promoting genes. When gibberellin levels increase, the DELLA proteins are targeted for ubiquitination and subsequent degradation by the proteasome. This removal releases the inhibition of transcription factors, allowing the plant to respond by stem.

234. (B) 20-24 nucleotides
Mature functional microRNAs are small, non-coding RNA molecules that play a central role in post-transcriptional gene regulation. In plants, these molecules are generally characterized by an approximate sequence length of 20 to 24 nucleotides. This specific size is a result of the precise processing of primary transcripts by Dicer-like enzymes. The microRNA then guides an effector complex to complementary targets.

235. (A) miRNA derivation from hairpin structures
The structural distinction between microRNAs and small interfering RNAs in plants relies primarily on their biogenesis and precursors. MicroRNAs are derived from single-stranded primary transcripts that fold into characteristic imperfectly base-paired hairpin structures. In contrast, small interfering RNAs originate from long, double-stranded RNA molecules. Both types of small RNAs are processed into similar sizes and function as key gene regulators.

236. (A) RAPD
The Random Amplified Polymorphic DNA technique is a molecular marker system that utilizes the polymerase chain reaction. It relies upon random, low-stringency PCR amplification

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By activating SOS1, the pathway facilitates the export of sodium.

254. (A) Vacuole and endoplasmic reticulum
Calcium ions function as universal secondary messengers in many plant signaling pathways. In plant cells, the major defined intracellular stores for releasable calcium are the vacuole and the endoplasmic reticulum. Upon stimulation by extracellular signals, calcium is rapidly released from these compartments into the cytoplasm, where it triggers various physiological and developmental responses through its interaction with various calcium-binding proteins.

255. (A) AUX/IAA
The regulatory mechanism governing auxin signaling depends on hormone perception linking directly to the targeted destruction of specific repressors. Upon binding auxin, the TIR1 receptor facilitates the interaction with AUX/IAA repressor proteins, leading to their ubiquitination and subsequent degradation by the 26S proteasome. The removal of these negative repressors allows auxin-responsive transcription factors to activate the expression of genes.

256. (A) The RISC (RNA-Induced Silencing Complex)
Endogenous small RNAs, such as microRNAs and small interfering RNAs, are essential regulators of gene expression in plants. To execute their function, these small RNAs are loaded into Argonaute proteins to form an effector complex known as the RNA-induced silencing complex. The RISC utilizes the small RNA sequence to identify and target complementary messenger RNA transcripts for cleavage or.

257. (A) RNA viral infections
Post-transcriptional gene silencing is a fundamental defense mechanism that recognizes double-stranded RNA as an abnormal signature. This indicates that PTGS originally evolved as a robust defense against RNA viral infections, which often involve the production of dsRNA intermediates during their replication cycle. By initiating the sequence-specific degradation of viral RNA, PTGS allows the plant to effectively limit viral spread.

258. (A) SNPs rely on single base changes
Single Nucleotide Polymorphism markers are highly favored in genetic studies because they represent variations at a single base position in the DNA sequence. Unlike standard SSR markers, which detect variations in the number of tandem repeats, SNPs are based on single base changes or small indels. This makes them exceptionally abundant and stable, providing high genomic resolution for diversity analysis.

259. (A) Foreground selection
When conducting marker-assisted backcrossing, researchers utilize two distinct sets of markers to accelerate the breeding process. The use of molecular markers that are tightly linked to the trait of interest from the donor parent constitutes foreground selection. This approach allows breeders to identify individuals carrying the target trait at early developmental stages, ensuring that the desired characteristic is successfully transferred.

260. (A) 147 bp of DNA wrapped around an octamer of histones
The nucleosome is the fundamental repeating unit of eukaryotic chromatin, providing a mechanism for packaging the genome within the nucleus. Each nucleosome core particle consists of approximately 147 base pairs of DNA wrapped around an octamer of core histone proteins. This octamer includes two copies each of histones H2A, H2B, H3, and H4. This organization is essential for compaction.

261. (A) Ty1-copia and Ty3-gypsy LTR retroelements
Transposable elements are major drivers of the C-value variation observed across plant species. LTR retroelements, particularly those from the Ty1-copia and Ty3-gypsy families, frequently accumulate into massive nested blocks within the genome. These elements utilize a copy-and-paste mechanism that leads to significant genome expansion over evolutionary time, contributing to the diversity of genomic architecture and total DNA content.

262. (A) Inverted repeats partitioning single-copy regions
The chloroplast and mitochondrial genomes of plants exhibit several distinct structural features. The dominant feature that separates the chloroplast genome from most plant mitochondrial genomes is the presence of two large inverted repeats. These repeats partition the plastome into large and small single-copy regions, providing structural stability

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and facilitating high-frequency intramolecular recombination. In contrast, mitochondrial genomes lack this characteristic configuration.

263. (A) Cytidine to Uridine
RNA editing in plant mitochondria is a critical post-transcriptional process that corrects inappropriate codons in gene transcripts. The majority of mitochondrial RNA editing events are characterized by the biochemical substitution of cytidine to uridine. This modification can generate functional start or stop codons and alter internal amino acids to match conserved protein sequences, ensuring the production of functional respiratory proteins.

264. (A) Within the 3' Untranslated Region (3' UTR)
The functional fine structure of active eukaryotic nuclear genes includes several essential functional sequences. The polyadenylation signal sequence, which is typically AAUAAA, is specifically located within the 3' untranslated region of the gene. This signal is recognized by the cleavage and polyadenylation machinery to dictate the exact termination point of the transcript and facilitate the addition of the tail.

265. (A) Protecting nascent transcripts from exonuclease degradation
During nuclear transcription, several mRNA processing steps are tightly coupled to the activity of RNA polymerase. The addition of a 5' cap structure provides a distinct functional advantage by protecting nascent transcripts from degradation by 5' exonucleases. Additionally, the cap is essential for facilitating nuclear export and ensuring the efficient recognition of the mature transcript by the translational machinery.

266. (A) Insensitivity to orientation and distance relative to the promoter
Enhancer sequences are critical cis-regulatory elements that govern the upregulation of gene expression. The defining unique property of an enhancer is its insensitivity to its orientation and physical distance relative to the promoter. Enhancers can function regardless of whether they are upstream or downstream of a gene, and they operate by providing binding sites for transcriptional activators that interact with.

267. (A) Express a toxic insecticidal protein exclusively in roots
Using a powerful constitutive promoter to drive a transgene ensures that the gene is expressed throughout the entire plant. However, this approach is inappropriate if the intended biotechnological goal is tissue-specific expression. For example, if a toxic insecticidal protein is needed exclusively in the roots to combat soil pests, a root-specific promoter would be required to avoid unwanted effects.

268. (A) Early NEP transcription to dominant PEP transcription
The developmental transition that controls chloroplast biogenesis relies on a shift in the activity of two distinct RNA polymerases. This process begins with early transcription by the nuclear-encoded polymerase, which focuses on genes for the plastid's genetic machinery. As the organelle matures, there is a transition to dominant transcription by the plastid-encoded polymerase, which transcribes genes for the photosynthetic apparatus.

269. (A) Introducing the corresponding functional nuclear restorer (Rf) allele
Restoring pollen fertility in a cytoplasmic male sterile line requires overcoming the deleterious effects of the mitochondrial mutations responsible for the trait. This is achieved by introducing the corresponding functional nuclear restorer allele into the plant's genome. The Rf genes encode proteins that are targeted to the mitochondria, where they modify or degrade the toxic transcripts, ensuring that normal development occurs.

270. (A) Molecular chaperonins acting in the chloroplast stroma
The efficient assembly of the complex Rubisco holoenzyme is a demanding process that occurs within the chloroplast stroma. It requires the assistance of specialized molecular chaperonins to prevent the aggregation of newly synthesized subunits and to facilitate their correct folding. This assistance is essential for the formation of the functional hexadecameric complex, which is critical for supporting the plant's photosynthetic.

271. (A) Extreme sensitivity to irreversible inactivation by oxygen
Symbiotic biological nitrogen fixation depends on the activity of the nitrogenase enzyme complex,

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which facilitates the reduction of atmospheric nitrogen to ammonia. A defining characteristic of nitrogenase is its extreme sensitivity to irreversible inactivation by oxygen. To protect this enzyme, diazotrophic organisms have evolved various strategies to maintain a low-oxygen environment within the nodules while still supporting high metabolic rates.

272. (A) Trimethylation of Histone H3 at Lysine 4 (H3K4me3)
Epigenetic control of gene expression in plants is achieved through various modifications to chromatin structure. While some modifications are associated with silencing, others correlate with activation. The trimethylation of histone H3 at the lysine 4 position is universally recognized as a mark of highly active euchromatin. This modification is typically localized to the promoter regions of genes that are active.

273. (A) Discovery of novel splice variants without prior knowledge
An advantage of utilizing RNA sequencing over traditional microarray technology is that RNA-seq does not require prior knowledge of the transcriptome. This allows for the discovery of novel splice variants and previously uncharacterized transcripts. Additionally, RNA-seq provides a wider dynamic range for quantifying transcript abundance and offers higher resolution for detecting gene expression changes across various tissues and developmental stages.

274. (A) Generate exceptionally long, continuous single-molecule reads
The PacBio Sequel system is a powerful third-generation sequencing platform that offers a unique advantage for genomic analysis. It has the capacity to generate exceptionally long, continuous single-molecule reads that can span several kilobases. These long reads are essential for accurately assembling complex and repetitive genomic regions, as they provide the long-range sequence information necessary to bridge gaps in assemblies.

275. (A) Prevent irreversible aggregation and assist in refolding
Heat shock proteins function as essential molecular chaperones during abiotic heat stress. Their primary protective role within the cell is to prevent the irreversible aggregation of denatured proteins and to assist in their refolding into functional structures. By maintaining protein homeostasis, HSPs protect cellular integrity and ensure survival under high-temperature conditions, allowing the plant to recover once the stress is.

276. (A) Extracellular binding, transmembrane helix, and intracellular kinase domains
Plant-specific receptor-like kinases are integral components of signaling pathways that allow cells to perceive and respond to extracellular stimuli. Structurally, these proteins consist of an extracellular domain for ligand binding, a single transmembrane helix, and an intracellular kinase domain. Upon activation by a specific ligand, the kinase domain phosphorylates target proteins to initiate a cellular response, ensuring proper growth and.

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277. (A) Ubiquitination by the SCF^{TIR1} complex after auxin binding
The targeted degradation of the AUX/IAA repressor proteins is a central event in auxin signaling. This process is dependent on their ubiquitination by the SCF TIR1 complex, which occurs only after auxin binds to the receptor. Once tagged with ubiquitin, the repressors are degraded by the 26S proteasome. This removal releases the inhibition of auxin-responsive transcription factors, thereby activating responses.

278. (A) Shared complementarity promotes AGO1-mediated slicing
MicroRNAs in plants are key post-transcriptional regulators that typically induce targeted transcript cleavage. This process occurs because the shared complementarity between the microRNA and its target transcript promotes the slicing activity of the Argonaute protein, primarily AGO1, within the silencing complex. This endonucleolytic cleavage leads to the rapid degradation of the target messenger RNA, effectively down-regulating the expression of genes.

279. (A) Isoelectric point and molecular mass
In proteomic analysis, two-dimensional gel electrophoresis is a fundamental technique used to separate proteins within a complex mixture. This method separates proteins based on two distinct physical properties: their isoelectric point in the first dimension and their molecular

deficit, allowing the plant to recover once water becomes available.

210. (C) I and III
Plant signaling kinase cascades are central to transmitting extracellular signals into the cell. These pathways involve a series of sequential phosphorylation events, where one kinase activates the next. This mechanism serves to amplify weak extracellular signals into robust intracellular responses, ensuring that the plant can adapt to environmental changes. A typical MAPK cascade requires multiple distinct kinases to function.

211. (A) Precise control of targeted protein destruction
The mechanism of hormone signaling via repressor degradation links hormone perception directly to the precise control of targeted protein destruction. When a hormone like auxin or gibberellin binds to its receptor, it initiates a process that marks specific repressor proteins for ubiquitination. These repressors are then degraded by the proteasome, allowing for the rapid activation of hormone-responsive gene expression.

212. (A) Slicing mRNA through AGO1-mediated guidance
Plant microRNAs are key post-transcriptional regulators that fine-tune gene expression levels. Their primary regulatory targeting mechanism involves the slicing of target messenger RNA transcripts. This process is achieved through the guidance of an Argonaute protein, typically AGO1, which uses the microRNA sequence to identify complementary targets. The resulting endonucleolytic cleavage leads to the rapid degradation of the target transcript.

213. (A) Double-stranded RNA viral intermediates
Virus-induced gene silencing is a powerful tool for functional validation that harnesses the plant's endogenous RNA interference machinery. The response is triggered by the presence of double-stranded RNA viral intermediates produced during the replication of the viral vector. These dsRNA molecules are processed into small interfering RNAs, which then guide the sequence-specific degradation of complementary host messenger RNA.

214. (A) Simple Sequence Repeats (SSRs)
Simple Sequence Repeat markers are highly effective tools for genetic analysis in plants. This marker system depends on identifying variations in the length of tandemly repeated core sequence blocks, typically one to six base pairs in length. These polymorphisms are easily detected through PCR amplification and fragment analysis, providing a co-dominant and highly reproducible method for mapping and diversity studies.

215. (A) Genomic DNA sequence
The core advantage of marker-assisted selection is its ability to bypass environmental influence on traits during the breeding process. This is possible because molecular markers detect variations directly at the level of the genomic DNA sequence, which is constant regardless of environmental conditions. This allows breeders to identify and select individuals with desirable genotypes at early developmental stages with high.

216. (A) Chromosomes occupy distinct spatial domains
Eukaryotic chromatin is not randomly organized within the nucleus; instead, it is structured into defined territories during interphase. These chromosome territories refer to the distinct spatial domains that each chromosome occupies. This organization is essential for regulating gene expression and maintaining genomic stability. The positioning of genes within these territories can influence their accessibility to the transcriptional and regulatory machinery.

217. (A) Fritillaria assyriaca
The C-value paradox is highlighted by the massive variation in genome sizes among plants of similar biological complexity. Fritillaria assyriaca is a notable example, possessing a genome that is vastly larger than that of Arabidopsis thaliana. This enormous size is primarily due to the accumulation of non-coding repetitive DNA, demonstrating that total DNA content does not correlate with organismal complexity.

218. (A) Rolling circle amplification and D-loop replication
The chloroplast genome primarily utilizes replication mechanisms that reflect its ancient bacterial origins. This involves rolling circle amplification and D-loop replication, which allow for the efficient production of multiple copies of

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transfer genetic information from well-studied model organisms to less-characterized crop species to improve breeding.

289. (A) Autopolyploid
An organism that possesses more than two complete sets of chromosomes derived from the same species is specifically termed an autopolyploid. This condition can result from the doubling of the genome within a single individual or through the fusion of unreduced gametes. Autopolyploidy is common in many plant species and can lead to increased biological vigor, larger cell sizes, and.

290. (A) Northern blotting
Northern blotting is a traditional molecular technique used to detect the presence and quantity of specific RNA molecules within a complex mixture. This process involves the separation of RNA fragments by size using gel electrophoresis, followed by their transfer to a membrane. A labeled nucleic acid probe is then used to hybridize to the target sequence, allowing for the visualization of levels.

291. (A) Gene density variation
The observation that the number of protein-coding genes does not necessarily scale with genome size is a characteristic of eukaryotic genomes. This genomic phenomenon is primarily due to gene density variation, where genes are separated by vast regions of non-coding repetitive DNA. Some large genomes are relatively gene-poor, while smaller genomes may be more compact, reflecting the evolutionary history of expansion.

292. (A) PEP carboxylase
In C4 plants, the initial fixation of atmospheric carbon dioxide is spatially separated from the Calvin cycle to minimize photorespiration. This process occurs in the mesophyll cells and is catalyzed by the enzyme PEP carboxylase. Unlike Rubisco, this enzyme has a high affinity for bicarbonate and does not react with oxygen, allowing the plant to concentrate carbon dioxide efficiently during photosynthesis.

293. (A) Possessing introns that require complex splicing
Eukaryotic nuclear genes exhibit several structural features that distinguish them from those in plastid or mitochondrial genomes. A primary distinction is the common presence of introns within the coding sequence, which must be precisely removed through complex splicing in the nucleus. Organellar genes, while sometimes containing introns, often lack this complexity and follow more prokaryotic-like patterns of gene organization and.

294. (A) Cyclic AMP (cAMP)
Cyclic AMP is a ubiquitous second messenger synthesized from ATP by the enzyme adenylyl cyclase. It plays a central role in relaying signals from cell surface receptors to various intracellular targets in many signaling pathways. By activating specific kinases and other effectors, cAMP integration allows the cell to respond to a wide range of extracellular stimuli, including hormones and environmental cues.

295. (A) Cytoplasmic (plastid) inheritance
The variegated leaf patterns in Mirabilis jalapa provided the first definitive evidence for the phenomenon of cytoplasmic inheritance. Because the plastids are inherited primarily through the maternal parent, the appearance of the progeny is determined by the types of plastids present in the egg cell. this discovery challenged traditional mendelian genetics and highlighted the importance of organellar genomes in determining plant phenotypes.

296. (A) Wobble hypothesis
The ability of a single tRNA species to recognize and bind to multiple codons that differ at the third base position is explained by the wobble hypothesis. This principle suggests that the base pairing at the third position of the codon is less stringent than at the first two positions. This flexibility allows for the efficient translation of the genetic code.

297. (A) Phenolic compounds such as acetosyringone
During Agrobacterium-mediated transformation, the plant-derived signals are essential for initiating the infection process. When a plant is wounded, it secretes phenolic compounds, such as acetosyringone, which are specifically perceived by the bacterial VirA protein. This recognition activates the vir gene system, leading to the processing and transfer of the T-DNA from the bacterium into the host plant's nuclear genome.

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(A) Diploid
(B) Monoploid/Haploid
(C) Triploid
(D) Tetraploid

2024

33. Gynogenesis refers to the in vitro production of haploid plants from which structure?
(A) Anther
(B) Unfertilized ovary
(C) Pollen grain
(D) Zygote

2007

34. Which phenomenon describes the generation of off-types from vegetatively propagated in vitro cultures?
(A) Somaclonal variation
(B) Somatic embryogenesis
(C) Organogenesis
(D) Habituation

2010

35. The primary advantage of double haploid technology in plant breeding is the rapid achievement of what state?
(A) Heterosis
(B) Polyploidy
(C) Homozygosity
(D) Aneuploidy

2019

36. Which structural barrier often necessitates the use of embryo rescue in interspecific crosses?
(A) Lack of anthers
(B) Excess pollen production
(C) Thickened seed coat
(D) Endosperm degeneration

2009

37. At what temperature does standard cryopreservation in liquid nitrogen occur?
(A) -20 degrees C
(B) -80 degrees C
(C) -196 degrees C
(D) -273 degrees C

2012

38. Select the correct sequence of steps involved in standard cryopreservation:
(A) Freezing, Pre-treatment, Storage, Thawing
(B) Pre-treatment, Freezing, Storage, Thawing
(C) Storage, Pre-treatment, Freezing, Thawing
(D) Thawing, Pre-treatment, Freezing, Storage

2005

39. What is the fundamental principle of cryopreservation for long-term tissue storage?
(A) Rapid acceleration of cellular metabolic rates
(B) Consistent induction of rapid cell division
(C) Controlled enhancement of tissue respiration
(D) Arrest of all internal metabolic activities

2016

40. Arrange the following steps of the vitrification process in the correct order:
1. Dehydration with cryoprotectant
2. Excision of explant
3. Plunge into liquid nitrogen
4. Rapid thawing

Which of the following represents the correct sequence?
(A) 2, 1, 3, 4
(B) 1, 2, 3, 4
(C) 2, 3, 1, 4
(D) 4, 3, 2, 1

2021

41. Which compound is universally used as a penetrating cryoprotectant?
(A) Agar
(B) Calcium chloride
(C) Dimethyl sulfoxide (DMSO)
(D) Gibberellic acid

2016

42. Vitrification in cryopreservation refers to the phase transition of water into what state?
(A) Amorphous glass
(B) Crystalline ice
(C) Supercooled liquid
(D) Gaseous vapor

2024

43. Why is the prevention of intracellular ice crystal formation critical during cryopreservation?
(A) Ice crystals accelerate the rate of metabolism
(B) Ice crystals cause localized cellular overheating
(C) Ice crystals degrade essential genomic DNA sequences
(D) Ice crystals physically rupture cellular membranes

2008

44. Non-penetrating cryoprotectants function primarily by performing which action?
(A) Entering the nucleus to protect DNA
(B) Inducing osmotic dehydration of the cell
(C) Binding to ribosomes

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CHAPTER 10
Plant Biotechnology / Genetic Engineering

2015

1. Which term describes the inherent capacity of a single plant cell to divide and regenerate into an entire plant?
(A) Pluripotency
(B) Totipotency
(C) Multipotency
(D) Unipotency

2009

2. What is the process by which mature differentiated plant cells revert to an unspecialized meristematic state?
(A) Dedifferentiation
(B) Redifferentiation
(C) Habituation
(D) Senescence

2008

3. Following dedifferentiation, what is the subsequent biological process where callus cells develop into specific organs like shoots or roots?
(A) Senescence
(B) Habituation
(C) Redifferentiation
(D) Elicitation

2025

4. Consider the following statements about cellular totipotency:
I. It relies on the genetic potential of the cell.
II. It requires appropriate exogenous stimuli like hormones.
III. It only occurs in animal cells.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

2009

5. In plant tissue culture, what is the primary role of an explant?
(A) To provide sterilized distilled water
(B) To supply essential inorganic nutrients
(C) To serve as the initial tissue source
(D) To regulate the incubation temperature

2003

6. Match the cellular processes in List I with their outcomes in List II:
List I : (Processes)
P. Dedifferentiation
Q. Redifferentiation
R. Plasmolysis
S. Totipotency
List II : (Outcomes)
1. Water loss
2. Whole plant regeneration
3. Callus formation
4. Organogenesis
(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-1, S-2
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-4, R-3, S-2

2025

7. Which factor is fundamentally responsible for enabling a somatic plant cell to express totipotency?
(A) Absence of a nucleus
(B) Presence of a rigid cell wall
(C) Loss of mitochondria
(D) Retention of the complete genome

2022

8. The initial discovery of totipotency is widely attributed to the culture of which plant tissue?
(A) Carrot phloem
(B) Tobacco pith
(C) Tomato leaf
(D) Onion root

2002

9. Identify the INCORRECT statement regarding dedifferentiation.
(A) It involves reentry into the cell cycle.
(B) It results in the formation of a callus.
(C) It is an irreversible process leading to cell death.
(D) It causes the loss of previously acquired specialized functions.

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298. (A) Heterosis
Heterosis, or hybrid vigor, describes the phenomenon where the progeny of two genetically diverse parents exhibit greater biological vigor, growth, or yield than either parent. This increased performance results from the combination of desirable alleles and the masking of deleterious recessive traits. Heterosis is widely exploited in plant breeding to develop high-yielding hybrid varieties that contribute significantly to global food production.

299. (A) Dideoxynucleoside triphosphates (ddNTPs)
The Sanger method of DNA sequencing relies fundamentally on the incorporation of dideoxynucleoside triphosphates to terminate chain elongation. These specialized molecules lack the 3' hydroxyl group necessary for the formation of a phosphodiester bond. By using fluorescently labeled ddNTPs, the sequencing process generates a collection of fragments of varying lengths that can be separated to reveal the underlying DNA sequence precisely.

300. (A) Single guide RNA (sgRNA)
In the CRISPR/Cas9 system, the specificity of genome editing is determined by the single guide RNA. This molecule is designed to have a sequence that is complementary to the target DNA, allowing it to guide the Cas9 nuclease to the precise genomic location. Once docked at the target site, the nuclease introduces a double-strand break, which can then be repaired.

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(B) P-1, Q-2, R-3, S-4
(C) P-2, Q-4, R-1, S-3
(D) P-3, Q-1, R-4, S-2

2012

21. Which element is a macronutrient required for the synthesis of chlorophyll and acts as an enzyme activator?
(A) Boron
(B) Zinc
(C) Magnesium
(D) Molybdenum

2002

22. What happens to plant tissue if the media pH drops below 4.5 during sterilization or culture?
(A) Nutrient uptake is maximized
(B) Agar fails to solidify properly
(C) Explant growth is accelerated
(D) Contamination is completely eliminated

2008

23. Which plant growth regulator is predominantly used to overcome dormancy in cultured embryos?
(A) 2,4-Dichlorophenoxyacetic acid
(B) Benzylaminopurine
(C) Naphthaleneacetic acid
(D) Gibberellic acid

2010

24. Activated charcoal is sometimes added to tissue culture media primarily to achieve which outcome?
(A) Adsorb toxic phenolic exudates
(B) Increase the level of light penetration
(C) Serve as a secondary carbon source
(D) Lower the freezing point of the media

2014

25. Consider the following statements on tissue culture applications:
I. Embryo rescue is used to recover distant hybrid crosses.
II. Anther culture is a method for haploid production.
III. Somaclonal variation provides novel genetic diversity.
IV. Endosperm culture generates diploid plants.
V. Ovule culture can prevent embryo abortion.
Which of the above statement(s) is/are correct?
(A) I, II, III and V
(B) I, II, IV and V
(C) I, III, IV and V
(D) II, III, IV and V

2001

26. Embryo rescue is most frequently applied to overcome which specific reproductive barrier?
(A) Post-zygotic incompatibility
(B) Pre-zygotic incompatibility
(C) Pollen tube bursting
(D) Stigmatic repulsion

2003

27. The production of double haploids involves generating haploids followed by chromosome doubling using which chemical agent?
(A) Ethyl methanesulfonate
(B) Sodium azide
(C) Polyethylene glycol
(D) Colchicine

2014

28. Which tissue is commonly cultured to produce triploid plants?
(A) Endosperm
(B) Pollen
(C) Nucellus
(D) Shoot tip

2025

29. Somaclonal variation arises primarily due to which factor in the tissue culture process?
(A) Utilization of liquid instead of solid media
(B) Cold storage periods of the donor explants
(C) Prolonged callus phase and high PGR levels
(D) Surface sterilization with sodium hypochlorite

2022

30. Determine the correct sequence for developing a homozygous fertile line via anther culture:
(A) Anther inoculation, Callus induction, Haploid regeneration, Chromosome doubling
(B) Chromosome doubling, Anther inoculation, Callus induction, Haploid regeneration
(C) Anther inoculation, Chromosome doubling, Callus induction, Haploid regeneration
(D) Callus induction, Anther inoculation, Chromosome doubling, Haploid regeneration

2001

31. Which explant is specifically targeted to produce virus-free plants?
(A) Appical meristem
(B) Mature leaf
(C) Root tip
(D) Stem internode

2001

32. What is the ploidy level of plants regenerated directly from microspores?

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2008

80. Match the vector type in List I with its approximate maximum insert capacity in List II:

List I : (Vector Type)

P. Plasmid
Q. Cosmid
R. BAC
S. YAC

List II : (Insert Capacity)

1. Up to 10 kb
2. Up to 45 kb
3. Up to 300 kb
4. Up to 1000 kb

(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-1, Q-3, R-2, S-4
(D) P-4, Q-2, R-3, S-1

2016

81. Which host organism is primarily utilized for the propagation of BAC vectors?
(A) Saccharomyces cerevisiae
(B) Escherichia coli
(C) Agrobacterium tumefaciens
(D) Bacillus subtilis

2012

82. In pBR322, insertion of foreign DNA into the BamHI site results in the loss of resistance to which antibiotic?
(A) Tetracycline
(B) Ampicillin
(C) Kanamycin
(D) Chloramphenicol

2021

83. Phagemids are vectors that contain origins of replication from plasmids and which other entity?
(A) Double-stranded phages
(B) Yeast
(C) Single-stranded phages
(D) Mammalian viruses

2006

84. Which structural component ensures stable segregation of YACs during yeast cell division?
(A) Telomere
(B) Origin of replication
(C) Multiple cloning site
(D) Centromere

2004

85. A genomic DNA library contains which type of genetic representation?
(A) Coding and non-coding genomic regions
(B) Exclusively expressed gene sequences
(C) Only ribosomal RNA genetic sequences
(D) Restricted promoter-specific regions

2017

86. Which enzyme is indispensable for the construction of a cDNA library?
(A) RNA polymerase
(B) Reverse transcriptase
(C) Taq polymerase
(D) Restriction endonuclease

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2009

87. A primary advantage of a cDNA library over a genomic library in expressing eukaryotic genes in bacteria is:
(A) Presence of introns which stabilize host expression
(B) Inclusion of native eukaryotic promoter sequences
(C) Lack of introns allowing bacterial translation
(D) Presence of specific eukaryotic enhancer sequences

2023

88. Oligo(dT) primers are used in cDNA synthesis to specifically bind to which structure?
(A) 5' cap of mRNA
(B) Ribosomal RNA subunits
(C) Intronic slice sites
(D) 3' poly(A) tail of mRNA

2009

89. Colony hybridization is a technique commonly used for what purpose?
(A) Screening DNA libraries for a specific gene
(B) Ligating DNA fragments
(C) Purifying plasmid DNA
(D) Inducing mutations in clones

2006

90. In the context of library screening, a radiolabeled or fluorescently tagged DNA fragment is known as a:
(A) Probe
(B) Primer
(C) Vector
(D) Adaptor

2007

91. Which formula is used to calculate the number of clones required to represent a genomic library with a specific probability?
(A) $N = \ln(P) \times f$
(B) $N = \dfrac{f}{(1-P)}$

(D) Raising the freezing point of water

2011

45. Rapid thawing of cryopreserved tissues is usually conducted at which temperature range to prevent ice recrystallization?
(A) 0 to 4 degrees C
(B) 10 to 15 degrees C
(C) 37 to 40 degrees C
(D) 60 to 65 degrees C

2016

46. Identify the INCORRECT statement regarding cryopreservation techniques.
(A) Slow cooling allows cells to dehydrate before freezing.
(B) Vitrification requires extremely high cooling rates.
(C) Meristems are ideal explants due to small cell size and lack of vacuoles.
(D) Cryoprotectants are highly toxic and are never removed after thawing.

2004

47. Which substance is a common non-penetrating cryoprotectant used alongside DMSO?
(A) Sucrose
(B) Glycerol
(C) Methanol
(D) Ethylene glycol

2002

48. The TTC (Triphenyl tetrazolium chloride) assay is performed post-cryopreservation to evaluate which parameter?
(A) Cell wall integrity
(B) Cell viability
(C) DNA mutation rate
(D) RNA degradation

2007

49. Which enzyme combination is typically required for successful plant protoplast isolation?
(A) DNAse and RNAse
(B) Cellulase and Pectinase
(C) Protease and Lipase
(D) Amylase and Ligase

2004

50. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : Somatic hybridization allows the crossing of sexually incompatible plant species.
Reason (R) : Protoplast fusion bypasses the sexual barriers of fertilization.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2006

51. What chemical agent is most extensively used to induce protoplast fusion?
(A) Sodium dodecyl sulfate (SDS)
(B) Ethylenediaminetetraacetic acid (EDTA)
(C) Polyethylene glycol (PEG)
(D) Polyvinylpyrrolidone (PVP)

2025

52. In somatic hybridization, a cybrid is defined as a cell containing what genetic configuration?
(A) Nuclei from both parents and cytoplasm from one parent
(B) Nuclei and cytoplasm from both parents
(C) Neither nuclei nor cytoplasm from the parents
(D) Nucleus from one parent and cytoplasm from both parents

2024

53. Which method is widely utilized for the electrical fusion of protoplasts?
(A) Electrophoresis
(B) Electroporation
(C) Electroblotting
(D) Electrofusion

2002

54. An essential osmoticum required during protoplast isolation to prevent cell bursting is:
(A) Ethanol
(B) Mannitol
(C) Agarose
(D) Acetic acid

2011

55. Asymmetric somatic hybrids are characterized by which phenomenon?
(A) Complete elimination of one parent's cytoplasm
(B) Equal fusion between both parental nuclei
(C) Fusion of three or more somatic protoplasts
(D) Partial or total loss of parental chromosomes

2023

56. Identify the primary limitation or disadvantage of somatic hybridization.
(A) Production of sterile or abnormal plants
(B) Absolute requirement for Agrobacterium

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2002

10. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : Callus tissue is composed of an unorganized mass of cells.
Reason (R) : Callus forms due to the redifferentiation of meristematic cells.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2004

11. Which primary cell type is most highly responsive to dedifferentiation stimuli?
(A) Sclerenchyma
(B) Tracheids
(C) Vessel elements
(D) Parenchyma

2022

12. Habituation in tissue culture refers to the phenomenon where cultures lose their requirement for which exogenous supplement?
(A) Carbon source
(B) Plant growth regulators
(C) Vitamins
(D) Micronutrients

2025

13. Which macronutrient acts as the primary nitrogen source in Murashige and Skoog (MS) media?
(A) Calcium chloride
(B) Magnesium sulfate
(C) Ammonium nitrate
(D) Potassium phosphate

2011

14. What is the most common carbon source utilized in standard plant tissue culture media?
(A) Glucose
(B) Fructose
(C) Maltose
(D) Sucrose

2024

15. Consider the following statements about plant growth regulators:
I. Auxins promote root initiation.
II. Cytokinins promote shoot multiplication.
III. Gibberellins are primarily used for somatic embryogenesis.
IV. High auxin to cytokinin ratio favors shoot development.
Which of the above statement(s) is/are INCORRECT?
(A) I and II
(B) II and III
(C) III and IV
(D) I and IV

2016

16. In tissue culture, the combination of 2,4-D and Kinetin is most frequently used to induce which response?
(A) Rooting
(B) Callus formation
(C) Shooting
(D) Flowering

2013

17. Which vitamin is considered essential for most plant tissue culture media?
(A) Riboflavin
(B) Thiamine
(C) Ascorbic acid
(D) Calciferol

2024

18. What is the primary function of agar in plant tissue culture?
(A) Acts as a solidifying agent
(B) Provides essential nutrients
(C) Adjusts the pH of the media
(D) Serves as a hormone

2018

19. Identify the correct pair of PGR and its primary function.
(A) Indole-3-acetic acid : Shoot elongation
(B) Abscisic acid : Seed germination
(C) Zeatin : Cell division
(D) Ethylene : Root initiation

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2018

20. Match the media components in List I with their respective roles in List II:
List I : (Components)
P. EDTA
Q. Sucrose
R. Myo-inositol
S. Kinetin
List II : (Roles)
1. Osmoticum and carbon
2. Iron chelation
3. Cell division
4. Vitamin-like growth enhancer
(A) P-2, Q-1, R-4, S-3

(C) They cut only single-stranded DNA.
(D) They recognize the same DNA sequence.

2001

69. The Klenow fragment retains which specific enzymatic activities?
(A) 3'→5' polymerase and 5'→3' exonuclease
(B) 5'→3' polymerase and 5'→3' exonuclease
(C) 5'→3' polymerase and 3'→5' exonuclease
(D) Only 5'→3' exonuclease

2017

70. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : Restriction enzyme digestion often leaves 'sticky ends'.
Reason (R) : Sticky ends facilitate efficient ligation by complementary base pairing.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2007

71. S1 nuclease functions primarily to cleave which specific substrate?
(A) Double-stranded DNA
(B) Proteins
(C) Lipids
(D) Single-stranded DNA and RNA

2008

72. Which enzyme adds phosphate groups to the 5' hydroxyl termini of DNA?
(A) T4 Polynucleotide kinase
(B) Alkaline phosphatase
(C) T4 DNA ligase
(D) Restriction endonuclease

2006

73. A critical feature of all cloning vectors is the presence of an origin of replication (ori). What is its function?
(A) It dictates the vector's specific antibiotic resistance
(B) It provides a site for restriction enzyme digestion
(C) It enables independent replication within the host
(D) It initiates the transcription of the inserted gene

2016

74. Plasmids used as cloning vectors typically carry selectable markers. What is their primary purpose?
(A) Identify host cells containing the specific plasmid
(B) Drastically increase the plasmid copy number
(C) Facilitate rapid downstream DNA sequencing
(D) Induce targeted mutations in the host genome

2012

75. Which vector is most appropriate for cloning large DNA fragments up to 300 kb?
(A) pBR322
(B) Bacterial Artificial Chromosome (BAC)
(C) Bacteriophage lambda
(D) Cosmid

2014

76. The pUC series of plasmids features a multiple cloning site (MCS) embedded within which gene?
(A) ampR
(B) lacZ'
(C) tetR
(D) neoR

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2006

77. Cosmids are hybrid vectors combining features of plasmids and which other element?
(A) Yeast centromeres
(B) Agrobacterium T-DNA
(C) Phage lambda cos sites
(D) Retroviral LTRs

2007

78. Which statement about Yeast Artificial Chromosomes (YACs) is INCORRECT?
(A) They possess a yeast centromere (CEN).
(B) They require a yeast origin of replication (ARS).
(C) They contain telomeric sequences.
(D) They are exclusively propagated in bacterial hosts.

2016

79. The maximum insert size accommodated by standard bacteriophage lambda replacement vectors is approximately:
(A) 5 kb
(B) 20 kb
(C) 100 kb
(D) 300 kb

vectors
(C) Total inability to cross distant species barriers
(D) Generation of strictly haploid cellular progeny

2004

57. Which selection system relies on the inability of parental protoplasts to grow in a specific media while hybrid protoplasts survive?
(A) Blue-white screening
(B) Visual marker genes
(C) Auxotrophic complementation
(D) Southern blotting

2022

58. The first interspecific somatic hybrid produced by protoplast fusion was generated between which species?
(A) Nicotiana glauca and Nicotiana langsdorffii
(B) Solanum tuberosum and Solanum lycopersicum
(C) Brassica oleracea and Brassica rapa
(D) Oryza sativa and Triticum aestivum

2014

59. Cybrids are particularly valuable for transferring which agronomic trait?
(A) Seed coat color
(B) Plant height
(C) Internode length
(D) Cytoplasmic male sterility

2018

60. During electrical fusion of protoplasts, what is the role of the alternating current (AC) field?
(A) To lyse the cell membrane
(B) To align the protoplasts into pearl chains
(C) To induce membrane breakdown
(D) To fuse the nuclei

2021

61. Restriction endonucleases naturally function in bacteria as a defense against what?
(A) Fungal infections
(B) Heavy metal toxicity
(C) Bacteriophage infections
(D) Thermal stress

2009

62. Which class of restriction enzymes is most commonly used in recombinant DNA technology?
(A) Type I
(B) Type II
(C) Type III
(D) Type IV

2008

63. EcoRI recognizes which specific DNA sequence?
(A) 5'-GGATCC-3'
(B) 5'-AAGCTT-3'
(C) 5'-GAATTC-3'
(D) 5'-CTGCAG-3'

2013

64. DNA ligase catalyzes the formation of which type of bond between adjacent nucleotides?
(A) Hydrogen bond
(B) Peptide bond
(C) Glycosidic bond
(D) Phosphodiester bond

2009

65. The enzyme Alkaline Phosphatase is used in cloning vectors to prevent what process?
(A) Self-ligation of the vector
(B) DNA degradation
(C) Transcription of the insert
(D) Primer annealing

2013

66. Match the DNA modifying enzymes in List I with their activities in List II:
List I : (Enzymes)
P. DNA Polymerase I
Q. Reverse Transcriptase
R. Polynucleotide Kinase
S. Terminal Deoxynucleotidyl Transferase
List II : (Activities)
1. Synthesizes DNA from RNA
2. Adds a phosphate group to the 5' end
3. Adds homopolymer tails to 3' ends
4. Synthesizes DNA from a DNA template
(A) P-4, Q-1, R-2, S-3
(B) P-1, Q-4, R-2, S-3
(C) P-4, Q-1, R-3, S-2
(D) P-1, Q-2, R-3, S-4

2014

67. Which enzyme is responsible for removing RNA primers during Okazaki fragment maturation in E. coli?
(A) DNA Polymerase III
(B) RNA Polymerase
(C) DNA Polymerase I
(D) DNA Helicase

2023

68. Isoschizomers are defined as restriction enzymes that share what characteristic?
(A) They have different recognition sites but leave the same overhang.
(B) They require RNA as a template.

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(C) $N = \frac{\ln(1-P)}{\ln(1-f)}$

(D) $N = P \times (1-f)$

2011

92. Identify the INCORRECT step in constructing a genomic library.
(A) Isolation of high molecular weight genomic DNA
(B) Partial digestion of genomic DNA with a restriction enzyme
(C) Ligation of DNA fragments into a suitable vector
(D) Synthesis of complementary DNA from an RNA template

2019

93. What is the role of adaptors or linkers in library construction?
(A) Add restriction sites to DNA fragments
(B) Provide an internal origin of replication
(C) Function as a primary selectable marker
(D) Methylate the host's genomic DNA

2014

94. Expression libraries are typically screened using which type of probe?
(A) DNA oligonucleotides
(B) Antibodies
(C) RNA primers
(D) Liposomes

2012

95. cDNA libraries are tissue-specific. What is the fundamental reason for this?
(A) Different tissues have different genomic DNA.
(B) Different tissues express different sets of mRNA.
(C) Different tissues use different genetic codes.
(D) Different tissues contain different restriction enzymes.

2016

96. Partial digestion of genomic DNA during library construction ensures what outcome?
(A) Complete destruction of introns
(B) Generation of overlapping DNA fragments
(C) Removal of all restriction sites
(D) Selection of only expressed genes

2004

97. In plant genetic engineering, what is the function of a promoter?
(A) Terminate the translation process
(B) Regulate the transcription of genes
(C) Splice introns from primary mRNA
(D) Degrade foreign genomic DNA

2013

98. Consider the following statements about constitutive promoters:
I. They drive gene expression continuously across most tissues.
II. The CaMV 35S promoter is a classic example.
III. They are activated only by specific environmental stresses.
Which of the above statement(s) is/are correct?
(A) I and II
(B) I and III
(C) II and III
(D) I, II and III

NODIA

2013

99. Which promoter would be best suited for expressing a gene exclusively in the roots of a transgenic plant?
(A) CaMV 35S
(B) Actin promoter
(C) RolD promoter
(D) Ubiquitin promoter

2019

100. Inducible promoters are characterized by their ability to do what?
(A) Express genes continuously
(B) Function only in seeds
(C) Terminate transcription
(D) Respond to specific endogenous or exogenous stimuli

2010

101. The napin promoter is commonly used for driving gene expression in which specific plant tissue?
(A) Seeds
(B) Roots
(C) Leaves
(D) Pollen

2021

102. Which pathogen is the natural source of the CaMV 35S promoter?
(A) Agrobacterium tumefaciens
(B) Cauliflower mosaic virus
(C) Tobacco mosaic virus
(D) Bacillus thuringiensis

2019

103. Why might a researcher choose a tissue-specific promoter over a constitutive promoter for expressing a pest-resistance gene?

(B) I, II, IV and V
(C) II, III, IV and V
(D) I, III, IV and V

2005

126. Sonication-assisted Agrobacterium-mediated transformation (SAAT) employs ultrasound waves for what purpose?
(A) Direct lysis of the bacterial cell walls
(B) Create micro-wounds in the plant tissue
(C) Precipitate DNA onto metal microcarriers
(D) Facilitate the fusion of plant protoplasts

2013

127. Which parameter is critical to optimize when using a helium-driven gene gun?
(A) Helium gas pressure
(B) Light intensity
(C) Media pH
(D) Agrobacterium concentration

2003

128. Direct gene transfer methods frequently result in which integration event compared to Agrobacterium?
(A) Exclusively single-copy insertions
(B) Higher frequency of multiple copy and rearranged insertions
(C) No genomic integration, only transient expression
(D) Precise homologous recombination at targeted loci

2003

129. Silicon carbide whiskers mediate gene transfer through which physical process?
(A) Electrical discharge
(B) Microscopic puncturing of cell walls during vortexing
(C) High-velocity bombardment
(D) Chemical dissolution of the membrane

2010

130. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : Chloroplast transformation is largely achieved via biolistics.
Reason (R) : Agrobacterium naturally transfers T-DNA specifically into the plastid genome.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2001

131. The primary challenge in using electroporation on intact plant cells is the presence of what structure?
(A) Plasma membrane
(B) Nucleus
(C) Cell wall
(D) Vacuole

2007

132. Liposome-mediated transformation (lipofection) involves encapsulating DNA in what type of structure?
(A) Protein coat
(B) Carbohydrate matrix
(C) Gold nanoparticle
(D) Artificial lipid vesicle

2021

133. Selectable markers in plant transformation are crucial for which process?
(A) Differentiate between transformed cells
(B) Visualize the location of specific proteins
(C) Enhance the rate of genomic DNA integration
(D) Activate the transcription of the promoter

2021

134. The nptII gene confers resistance to which class of antibiotics?
(A) Penicillins
(B) Aminoglycosides (e.g., Kanamycin)
(C) Tetracyclines
(D) Macrolides

2008

135. Which gene is widely used as a reporter to produce a blue coloration in the presence of the substrate X-Gluc?
(A) GFP
(B) Luciferase
(C) hpt
(D) GUS (uidA)

2023

136. Unlike GUS, what is the primary advantage of using the Green Fluorescent Protein (GFP) as a reporter?
(A) Non-destructive in vivo visualization
(B) Requirement for a toxic dye substrate
(C) Conferred antibiotic resistance marker
(D) Enzymatic amplification of the signal

2013

137. The bar gene, used as a selectable marker, confers resistance to which herbicidal compound?
(A) Glyphosate
(B) Atrazine

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2005

115. Consider the following statements about binary vectors in Agrobacterium-mediated transformation:
I. They consist of two separate plasmids.
II. The T-DNA and vir genes are on the same plasmid.
III. The helper plasmid contains the vir genes but lacks T-DNA.
IV. They allow easier cloning in E. coli prior to transfer to Agrobacterium.
Which of the above statement(s) is/are correct?
(A) I, II and IV
(B) I, III and IV
(C) II, III and IV
(D) I, II and III

2007

116. Natural T-DNA carries genes for the synthesis of plant hormones. Which hormones are these?
(A) Auxin and Gibberellin
(B) Cytokinin and Ethylene
(C) Abscisic acid and Gibberellin
(D) Auxin and Cytokinin

2019

117. Opines are synthesized by transformed plant cells to serve what function?
(A) Nutrient source for Agrobacterium
(B) Defensive toxins against insect pests
(C) Growth regulators for the plant host
(D) Structural components of the cell wall

2025

118. Consider the following vir genes:
I. virA
II. virG
III. virB
IV. virD1
V. virE2
Which combination of genes constitutes the two-component regulatory system sensing plant signals?
(A) I and II
(B) III and IV
(C) IV and V
(D) I and V

2010

119. In Agrobacterium-mediated transformation of floral dip, which plant is the primary model organism used?
(A) Nicotiana tabacum
(B) Oryza sativa
(C) Zea mays
(D) Arabidopsis thaliana

2003

120. Disarming a Ti plasmid involves the removal of which genes to prevent disease while allowing gene transfer?
(A) All virulence-associated vir genes
(B) The internal origin of replication
(C) The left and right border sequences
(D) Oncogenes for auxin/cytokinin synthesis

2013

121. Biolistics, or the gene gun method, relies on coating DNA onto microcarriers made of which metals?
(A) Iron or Copper
(B) Silver or Platinum
(C) Gold or Tungsten
(D) Zinc or Magnesium

2007

122. Electroporation facilitates direct gene transfer by using which mechanism?
(A) High-velocity physical bombardment
(B) Short electrical pulses to create transient membrane pores
(C) Chemical permeabilization with PEG
(D) Direct physical injection with a microscopic needle

2003

123. Microinjection is a technique primarily used for transforming which biological target?
(A) Intact leaves
(B) Bacterial colonies
(C) Whole seeds
(D) Single cells or protoplasts

2002

124. Which major advantage does biolistics hold over Agrobacterium-mediated transformation?
(A) Naturally targets the plant nucleus
(B) Prevents multiple copy integrations
(C) Requires no specialized lab equipment
(D) Effective for recalcitrant monocots

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2011

125. Consider the following statements on direct gene transfer:
I. PEG-mediated transfer requires protoplasts.
II. Biolistics can transform chloroplasts.
III. Electroporation works efficiently on intact thick-walled cells.
IV. Microinjection requires a micromanipulator.
V. Direct transfer often results in complex integration patterns.
Which of the above statement(s) is/are correct?
(A) I, II, III and V

2021

149. In a Southern blot, transferring DNA from the agarose gel to a nitrocellulose or nylon membrane is facilitated by which process?
(A) Standard high-speed centrifugation
(B) Specific DNA polymerase activity
(C) Capillary action or electro-transfer
(D) Enzymatic DNA ligase activity

2017

150. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : Western blotting confirms the presence of the transgenic protein in the host plant.
Reason (R) : Western blotting detects DNA integration events at the chromosomal level.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2022

151. Which fluorescent dye is most commonly used as a non-specific intercalating agent in real-time PCR assays?
(A) Ethidium bromide
(B) TaqMan probe
(C) X-Gal
(D) SYBR Green I

2016

152. To determine the exact copy number of a transgene integrated into the plant genome, which technique is most conclusive?
(A) Southern blot
(B) Northern blot
(C) Western blot
(D) RT-PCR

2007

153. During Southern blotting, DNA is typically denatured into single strands using which chemical?
(A) Ethanol
(B) Hydrochloric acid (HCl)
(C) Phenol
(D) Sodium hydroxide (NaOH)

2001

154. Reverse Transcriptase PCR (RT-PCR) is an essential prerequisite for assessing what aspect of a transgene?
(A) Transgene mRNA expression levels
(B) Transgene copy number
(C) Transgene integration site
(D) Transgene protein folding

2015

155. Which component ensures target specificity when using TaqMan chemistry in real-time PCR?
(A) Use of non-specific intercalating dyes
(B) Application of heat-stable RNA polymerase
(C) High concentrations of magnesium ions
(D) Probes complementary to the target sequence

2024

156. The Ct (Cycle threshold) value in real-time PCR is inversely proportional to what factor?
(A) The physical size of the amplicon
(B) The optimal reaction temperature
(C) The length of the synthetic primer
(D) The initial amount of nucleic acid

2010

157. RNA interference (RNAi) is a biological process in which RNA molecules inhibit gene expression primarily by what mechanism?
(A) Preventing DNA replication
(B) Mutating the promoter sequence
(C) Degrading target mRNA
(D) Enhancing translation

2022

158. Select the correct sequence of molecular events in the RNAi pathway:
(A) Dicer cleavage, dsRNA formation, RISC assembly, mRNA degradation
(B) dsRNA formation, Dicer cleavage, RISC assembly, mRNA degradation
(C) RISC assembly, dsRNA formation, Dicer cleavage, mRNA degradation
(D) dsRNA formation, RISC assembly, Dicer cleavage, mRNA degradation

2001

159. Which enzyme is responsible for cleaving long double-stranded RNA into short interfering RNAs (siRNAs)?
(A) Dicer
(B) Argonaute
(C) RNA Polymerase II
(D) Reverse Transcriptase

2004

160. MicroRNAs (miRNAs) are typically derived from which specific precursor structure?
(A) Long perfectly paired dsRNA

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(C) Phosphinothricin (Glufosinate)
(D) Paraquat

2013

138. Which specific substrate is oxidized to emit light in the bioluminescent reporter system derived from the firefly?
(A) Luciferin
(B) X-Gal
(C) NPTII
(D) Hygromycin

2017

139. Identify the INCORRECT statement regarding reporter genes.
(A) They are used to study promoter activity.
(B) They help confirm the spatial and temporal expression of transgenes.
(C) They are strictly required for the survival of transformed cells.
(D) GUS assays typically require destructive sampling of tissue.

2017

140. Match the marker/reporter gene in List I to its characteristic feature in List II:
List I : (Genes)
P. hpt
Q. GFP
R. GUS
S. PMI
List II : (Features)
1. Requires UV/blue light for visualization
2. Requires X-Gluc substrate for assay
3. Confers resistance to hygromycin
4. Phosphomannose isomerase positive selection
(A) P-3, Q-1, R-2, S-4
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-2, R-1, S-4
(D) P-2, Q-3, R-1, S-4

2001

141. Positive selection markers, such as PMI, function by what mechanism?
(A) Use of antibiotics to kill the untransformed cells
(B) Emission of specific wavelengths of fluorescence
(C) Utilization of a unique metabolic growth substrate
(D) Induction of programmed cell death in transformed cells

2004

142. The uidA gene encodes which specific enzyme?
(A) Beta-galactosidase
(B) Neomycin phosphotransferase
(C) Hygromycin phosphotransferase
(D) Beta-glucuronidase

2002

143. Which reporter gene, often used in early plant transformation studies, encodes an enzyme that inactivates an antibiotic by acetylation?
(A) Luciferase
(B) GUS
(C) GFP
(D) CAT

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2007

144. The EPSPS gene mutation is utilized as a selectable marker for resistance to which agent?
(A) Kanamycin
(B) Glyphosate
(C) Glufosinate
(D) Bialaphos

2016

145. Southern blotting is a molecular technique utilized to verify the integration of which macromolecule?
(A) RNA
(B) DNA
(C) Protein
(D) Lipid

2019

146. Northern blotting is specifically designed to analyze the expression of which target?
(A) Messenger RNA
(B) Genomic DNA
(C) Recombinant proteins
(D) Primary metabolites

2014

147. In Western blotting, what type of probe is used to detect the target molecule?
(A) Radiolabeled DNA
(B) Antisense RNA
(C) Specific antibodies
(D) Intercalating dyes

2008

148. Real-time PCR (qPCR) differs from conventional PCR primarily by enabling what capability?
(A) Amplification of RNA templates directly
(B) Ligation of specific DNA fragment ends
(C) Digestion of target DNA using enzymes
(D) Quantification of DNA during amplification

(A) Maximize the metabolic drain on the entire host plant
(B) Increase the overall physical size of the whole plant
(C) Restrict protein expression to vulnerable tissues
(D) Inhibit the development of the primary root system

2023

104. The maize ubiquitin promoter (Ubi-1) is frequently utilized as a constitutive promoter in which group of plants?
(A) Monocots
(B) Dicots
(C) Gymnosperms
(D) Bryophytes

2013

105. A heat-shock promoter is an example of which classification of promoters?
(A) Inducible
(B) Constitutive
(C) Tissue-specific
(D) Synthetic

2012

106. Identify the INCORRECT pairing of a promoter and its classification.
(A) Phaseolin - Constitutive
(B) CaMV 35S - Constitutive
(C) rd29A - Stress-inducible
(D) RBCS - Light-inducible

2005

107. Synthetic promoters are engineered by combining elements such as the core promoter and what other regulatory sequences?
(A) Introns
(B) Exons
(C) Cis-acting elements
(D) Stop codons

2011

108. Consider the following statements on promoters:
I. Monocot promoters are highly efficient in dicots.
II. Introns can enhance promoter efficiency in monocots.
III. The NOS promoter is derived from Agrobacterium.
IV. Promoters function by binding RNA polymerase.
Which of the above statement(s) is/are correct?
(A) I, II and III
(B) II, III and IV
(C) I, III and IV
(D) I, II, III and IV

2021

109. Agrobacterium tumefaciens induces which disease in susceptible dicotyledonous plants?
(A) Crown gall disease
(B) Powdery mildew
(C) Hairy root disease
(D) Leaf spot

2001

110. Which specific component of the Ti plasmid is transferred and integrated into the plant genome?
(A) Virulence (vir) region
(B) Origin of replication
(C) T-DNA
(D) Opine catabolism genes

2022

111. The transfer of T-DNA is delineated by two specific sequences known as:
(A) Left and Right borders
(B) Promoter and Terminator
(C) VirA and VirG
(D) Origin and Centromere

2014

112. Which phenolic compound released by wounded plant cells naturally activates the vir genes of Agrobacterium?
(A) Ethylene
(B) Salicylic acid
(C) Jasmonic acid
(D) Acetosyringone

2025

113. Within the Agrobacterium vir operon, which protein acts as an endonuclease to nick the T-DNA at the border sequences?
(A) VirD2
(B) VirA
(C) VirG
(D) VirE2

2004

114. What is the function of the VirE2 protein during T-DNA transfer?
(A) It coats the single-stranded T-DNA, protecting it from nucleases.
(B) It acts as a sensor kinase.
(C) It forms a channel in the bacterial membrane.
(D) It synthesizes opines.

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(B) Ribosomal RNA
(C) Transfer RNA
(D) Single-stranded RNA forming hairpin loop structures

2009

161. In the RISC complex, which catalytic protein is responsible for slicing the target mRNA?
(A) Dicer
(B) Argonaute
(C) Drosha
(D) Helicase

2016

162. How do siRNAs primarily differ from miRNAs regarding target specificity in plants?
(A) siRNAs typically have perfect complementarity to their target, leading to mRNA cleavage.
(B) siRNAs only inhibit translation without cleaving mRNA.
(C) miRNAs target DNA directly.
(D) miRNAs are exogenously introduced, while siRNAs are strictly endogenous.

2002

163. The phenomenon of co-suppression in transgenic petunias (producing white flowers instead of deep purple) was an early observation of which mechanism?
(A) Homologous recombination
(B) Transposon tagging
(C) RNA interference
(D) Point mutation

2016

164. To engineer virus resistance via RNAi, plants are typically transformed with constructs that transcribe which structure?
(A) Antisense RNA
(B) Sense RNA
(C) Ribozymes
(D) Hairpin RNA (hpRNA)

2009

165. Viral Suppressors of RNA Silencing (VSRs) are proteins produced by viruses for what purpose?
(A) To enhance host Dicer activity
(B) To integrate viral DNA into the host genome
(C) To overcome the plant's RNAi defense mechanism
(D) To increase viral mutation rates

2016

166. Match the RNAi components in List I with their functional characteristics in List II:

List I : (Components)
P. Dicer
Q. Argonaute
R. siRNA
S. miRNA

List II : (Characteristics)
1. Slicer activity in RISC
2. Endogenous regulator of development
3. RNase III-like enzyme
4. Perfectly complementary 21-24 nt RNA

(A) P-3, Q-1, R-4, S-2
(B) P-1, Q-3, R-2, S-4
(C) P-3, Q-1, R-2, S-4
(D) P-1, Q-4, R-3, S-2

2013

167. RNA-directed DNA methylation (RdDM) is an epigenetic mechanism guided by which small RNA molecules?
(A) 21-nt miRNAs
(B) tRNAs
(C) rRNAs
(D) 24-nt siRNAs

2004

168. Which feature is characteristic of RNAi transmission in plants compared to animals?
(A) It can move systemically through the phloem to distant tissues.
(B) It is strictly confined to the cell where it originates.
(C) It only occurs in the eyes.
(D) It requires direct cell-to-cell fusion.

2021

169. Site-directed mutagenesis is a molecular biology method used to achieve what outcome?
(A) Introduce random mutations across the genome
(B) Delete entire chromosomes
(C) Create specific, targeted alterations in a known DNA sequence
(D) Replicate DNA without mutations

2004

170. Oligonucleotide-directed mutagenesis typically utilizes a synthetic primer that contains what feature?
(A) A sequence with a desired mismatch
(B) A completely complementary sequence
(C) A poly-A tail
(D) An RNA polymerase promoter

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2021

171. In PCR-based site-directed mutagenesis using the QuikChange method, what is the role of the DpnI enzyme?
(A) It cleaves the newly synthesized, unmethylated DNA.
(B) It ligates the mutated plasmids.
(C) It adds phosphate groups to primers.
(D) It cleaves the parental, methylated DNA template.

2012

172. Why is a high-fidelity DNA polymerase critical for PCR-based site-directed mutagenesis?
(A) It synthesizes DNA faster than regular polymerases.
(B) It incorporates random mutations efficiently.
(C) It functions at lower temperatures.
(D) It possesses 3' to 5' proofreading activity, preventing unintended secondary mutations.

2001

173. Identify the INCORRECT statement regarding oligonucleotide-directed mutagenesis.
(A) It can only be used to create single base substitutions, not deletions or insertions.
(B) It requires a template DNA sequence.
(C) The mismatch in the primer becomes incorporated into the newly synthesized strand.
(D) It typically involves a transformation step into E. coli to recover the mutant plasmid.

2022

174. Overlap extension PCR is a mutagenesis strategy that uniquely requires how many primers to generate a mutated fragment?
(A) Two
(B) Three
(C) Four
(D) Six

2018

175. Cassette mutagenesis involves which of the following processes?
(A) Removing a fragment of DNA with restriction enzymes and replacing it with a synthetic, mutated double-stranded DNA sequence
(B) Using UV light to induce mutations in a specific cassette
(C) Inserting a transposable element randomly
(D) Transforming plant cells with a cassette tape

2011

176. Which condition represents a prerequisite for designing primers for site-directed mutagenesis?
(A) Primers must lack any GC nucleotide content
(B) Primers must bind to random sites on plasmids
(C) Primers must be complementary to the same strand
(D) Mutation should be located near the primer center

2010

177. The uracil-DNA glycosylase (UDG) based method of mutagenesis (Kunkel method) utilizes an E. coli strain deficient in which enzyme?
(A) DNA ligase
(B) dUTPase (dut-)
(C) RNA polymerase
(D) Restriction endonuclease

2024

178. What determines the mutation efficiency in the QuikChange mutagenesis protocol?
(A) Complete digestion of the parental template by DpnI
(B) The use of Taq polymerase
(C) The size of the host cell
(D) The concentration of agar

2013

179. Site-directed mutagenesis is most frequently applied in biotechnology for which purpose?
(A) Extracting total genomic DNA
(B) Visualizing cellular organelles
(C) Protein engineering to alter enzyme activity or stability
(D) Counting chromosome numbers

NODIA

2013

180. A deletion mutation can be achieved via PCR mutagenesis by designing primers that possess what characteristic?
(A) They contain extra nucleotides in the middle.
(B) They bind only to RNA.
(C) They are extremely short (less than 10 bases).
(D) They span the sequence to be deleted, omitting it from the amplicon.

2025

181. In the CRISPR-Cas9 system, what dictates the specific genomic target sequence for cleavage?
(A) The protospacer adjacent motif (PAM) exclusively
(B) The Cas9 protein structure
(C) The single guide RNA (sgRNA)
(D) The homologous recombination template

2003

182. Cas9 is best described as which type of enzyme?
(A) DNA ligase
(B) RNA-guided DNA endonuclease
(C) Reverse transcriptase
(D) RNA polymerase

2013

183. Which short DNA sequence is absolutely required immediately downstream of the target site for Cas9 to initiate cleavage?
(A) TATA box
(B) Poly-A signal
(C) Origin of replication
(D) Protospacer Adjacent Motif (PAM)

2001

184. TALENs recognize specific DNA sequences through modular repeats of amino acids. How many base pairs are recognized by a single TAL effector repeat?
(A) One
(B) Two
(C) Three
(D) Four

2017

185. Zinc Finger Nucleases (ZFNs) achieve DNA cleavage by utilizing the nuclease domain from which restriction enzyme?
(A) EcoRI
(B) BamHI
(C) FokI
(D) HindIII

2016

186. Double-strand breaks (DSBs) induced by genome editing tools are predominantly repaired by which error-prone cellular pathway, leading to gene knockouts?
(A) Non-Homologous End Joining (NHEJ)
(B) Homology-Directed Repair (HDR)
(C) Base Excision Repair (BER)
(D) Mismatch Repair (MMR)

2005

187. Homology-Directed Repair (HDR) is specifically utilized in genome editing to achieve what outcome?
(A) Generation of random frame-shift mutations
(B) Facilitation of foreign DNA degradation
(C) Precise gene insertion or replacements
(D) Deletion of the entire target chromosome

2016

188. Which characteristic distinguishes CRISPR-Cas9 from ZFNs and TALENs?
(A) It requires engineering a new protein for every specific DNA target.
(B) It cannot induce double-strand breaks.
(C) It functions exclusively in bacterial cells.
(D) It relies on RNA-DNA base pairing for target recognition.

2013

189. A dead Cas9 (dCas9) lacks endonuclease activity. It is commonly fused with transcriptional activators or repressors for what purpose?
(A) Gene interference or activation
(B) Permanent gene editing events
(C) Automated DNA sequencing runs
(D) Inducing specific DNA mutations

2007

190. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : CRISPR-Cas9 allows for multiplex gene editing.
Reason (R) : Multiple guide RNAs can be delivered simultaneously with a single Cas9 nuclease.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2019

191. Base editing technologies utilize a modified Cas9 fused to which type of enzyme to convert a single base without causing a double-strand break?
(A) Cytidine or adenine deaminases
(B) Standard DNA ligase enzymes
(C) General exonuclease proteins
(D) DNA polymerase-based systems

2007

192. Off-target effects in CRISPR-Cas9 refer to which unintended occurrence?
(A) Failure of the guide RNA to enter the host cell
(B) Lethal toxicity to the transformed plant tissue
(C) Loss of the catalytic activity of Cas9 protein
(D) Cleavage of DNA sequences similar to the target

2015

193. Bacillus thuringiensis produces insecticidal crystal proteins known as Cry proteins during which phase of its life cycle?

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(A) Exponential growth
(B) Sporulation
(C) Germination
(D) Conjugation

2001

194. The specific toxicity of Bt Cry proteins to insect pests is determined primarily by the presence of what in the insect gut?
(A) Specific cell surface receptors in the midgut epithelium
(B) High acidity (pH < 4)
(C) Absence of proteases
(D) High oxygen concentration

2005

195. Cry1Ac is highly toxic to insects belonging to which order?
(A) Coleoptera
(B) Diptera
(C) Lepidoptera
(D) Hemiptera

2021

196. Why are Cry proteins harmless to mammals and humans?
(A) Humans rapidly degrade the protein before it enters the stomach.
(B) The protein is inherently non-toxic to all animals.
(C) The acidic environment of the human stomach enhances the protein's nutritional value.
(D) Humans lack the specific midgut receptors and alkaline gut pH required for activation.

2001

197. Which type of enzyme is engineered into plants to disrupt insect digestion by blocking dietary protein breakdown?
(A) Chitinases
(B) Amylases
(C) Proteinase inhibitors
(D) Lipases

2019

198. Consider the following statements about Bt crops:
I. Bt cotton is cultivated to control the cotton bollworm.
II. Cry proteins act by forming pores in the insect midgut membrane.
III. Bt crops require higher applications of chemical insecticides.
Which of the above statement(s) is/are correct?
(A) I and III
(B) II and III
(C) I and II
(D) I, II and III

2009

199. To prevent or delay the evolution of resistance to Bt toxins in insect populations, which strategy is legally mandated for farmers?
(A) Application of extra chemical pesticides
(B) Premature harvesting of the entire crop
(C) Planting a refuge of non-Bt crop plants
(D) Increasing the standard dose of fertilizer

2019

200. Match the Cry protein class in List I with its primary target insect order in List II:
List I : (Cry Protein)
P. Cry1
Q. Cry3
R. Cry4
S. Vip3A
List II : (Target Insect Order)
1. Diptera (mosquitoes)
2. Coleoptera (beetles)
3. Lepidoptera (caterpillars)
4. Broad-spectrum vegetative insecticidal protein
(A) P-3, Q-2, R-1, S-4
(B) P-1, Q-2, R-3, S-4
(C) P-3, Q-1, R-2, S-4
(D) P-2, Q-3, R-1, S-4

2018

201. Which modification was necessary to achieve high-level expression of bacterial cry genes in transgenic plants?
(A) Adding introns to the gene sequence
(B) Removal of the upstream promoter
(C) Matching the plant codon usage bias
(D) Converting DNA to RNA before insertion

2011

202. The cowpea trypsin inhibitor (CpTI) gene confers resistance to insects by targeting which physiological process?
(A) Protein digestion in the gut
(B) Nerve signal transmission
(C) Midgut membrane integrity
(D) Molting and ecdysis

2007

203. Gene pyramiding in Bt crops involves which approach?
(A) Inserting genes in a pyramid-shaped vector
(B) Using genes from multiple plant species
(C) Stacking genes to delay insect resistance

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(D) Promoting vertical plant growth architecture

2021

204. Vegetative insecticidal proteins (Vip) differ from Cry proteins in what fundamental way?
(A) Toxic to various mammal species
(B) No requirement for insect ingestion
(C) Target the insect chitin exoskeleton
(D) Secreted during vegetative growth

2017

205. Coat-protein mediated resistance (CPMR) in plants is a classic example of which concept?
(A) Pathogen-derived resistance
(B) Systemic acquired resistance
(C) Hypersensitive response
(D) Gene-for-gene resistance

2022

206. Transgenic expression of viral coat proteins generally prevents viral infection by interfering with which early step of the viral life cycle?
(A) Viral transcription
(B) Viral assembly
(C) Viral release
(D) Viral uncoating

2009

207. Pathogenesis-related (PR) proteins are naturally produced by plants in response to what?
(A) Pathogen attack
(B) Drought stress
(C) Heat shock
(D) Nitrogen deficiency

2019

208. Consider the following groups of PR proteins:
I. PR-2 (beta-1,3-glucanases)
II. PR-3 (chitinases)
III. PR-10 (ribonuclease-like)
IV. PR-12 (defensins)
Which of the above statement(s) directly target and degrade fungal cell walls?
(A) I and II
(B) II and III
(C) III and IV
(D) I and IV

2009

209. The first commercially approved virus-resistant transgenic crop was engineered to resist which virus?
(A) Tomato spotted wilt virus
(B) Papaya ringspot virus
(C) Tobacco mosaic virus
(D) Potato virus Y

2016

210. Chitinases are frequently utilized in transgenic plants to confer resistance against which group of organisms?
(A) Fungi
(B) Viruses
(C) Bacteria
(D) Nematodes

2002

211. Defensins are small, cysteine-rich peptides that exert antimicrobial activity primarily by which mechanism?
(A) Inhibiting RNA synthesis
(B) Degrading DNA
(C) Disrupting microbial cell membranes
(D) Blocking viral uncoating

2017

212. Which transgenic strategy relies on a defective viral enzyme to compete with the functional wild-type viral enzyme, inhibiting replication?
(A) Coat-protein resistance
(B) Ribozyme expression
(C) RNAi
(D) Replicase-mediated resistance

2017

213. Polygalacturonase-inhibiting proteins (PGIPs) are engineered into plants to counteract which virulence factor secreted by necrotrophic fungi?
(A) Cell wall-degrading enzymes
(B) Chitin synthase activity
(C) Necrotrophic fungal toxins
(D) Molecular pathogen effectors

2022

214. Identify the INCORRECT statement regarding the application of RNAi for viral resistance.
(A) It targets sequence-specific viral RNAs for degradation.
(B) It results in broad-spectrum resistance against entirely unrelated viruses.
(C) It relies on the plant's endogenous RISC machinery.
(D) It involves the generation of viral-specific siRNAs.

2006

215. Consider the following strategies for engineering fungal resistance:
I. Overexpression of chitinase
II. Overexpression of glucanase
III. Expression of phytoalexin biosynthesis genes
IV. Expression of viral coat proteins
Which of the above statement(s) represent valid

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2010

260. Match the post-harvest trait in List I with its target gene/enzyme in List II:

List I : (Post-Harvest Trait)

P. Delayed softening
Q. Delayed ripening
R. Non-browning
S. High oleic oil

List II : (Target Gene/Enzyme)

1. Polyphenol oxidase
2. FAD2
3. Polygalacturonase
4. ACC synthase

(A) P-3, Q-4, R-1, S-2
(B) P-4, Q-3, R-2, S-1
(C) P-3, Q-1, R-4, S-2
(D) P-1, Q-4, R-3, S-2

2025

261. High laurate canola was developed to provide an alternative source of lauric acid, traditionally obtained from which tropical oils?

(A) Olive and Sunflower oil
(B) Corn and Soybean oil
(C) Coconut and Palm kernel oil
(D) Peanut and Sesame oil

2022

262. In antisense technology, the RNA transcribed from the introduced transgene is complementary to what?

(A) Ribosomal RNA
(B) The endogenous target mRNA
(C) The promoter sequence
(D) The transfer RNA

2022

263. Identify the primary advantage of delayed-ripening transgenic tomatoes for the agricultural supply chain.

(A) Harvesting the green fruit for transport
(B) Requiring less water during cultivation
(C) Eliminating the need for refrigeration
(D) Allowing vine-ripening for better flavor

2005

264. Why is silencing polyphenol oxidase (PPO) beneficial in potato processing?

(A) Prevent black spot bruising in tubers
(B) Drastically increase starch content
(C) Enhance resistance to potato blight
(D) Speed up the commercial frying process

2008

265. In the context of biotechnology, biosafety primarily addresses the assessment and management of risks associated with what?

(A) Regulate use of chemical fertilizers
(B) Manage traditional plant breeding methods
(C) Manage GMO risks to health/environment
(D) Control farm machinery operation safety

2017

266. Match the Indian regulatory authority in List I with its core function in List II:

List I : (Regulatory Authority)

P. IBSC
Q. RCGM
R. GEAC
S. FSSAI

List II : (Core Function)

1. Monitors research at the institutional level
2. Approves small-scale confined field trials
3. Regulates large-scale trials and commercial release
4. Regulates GM foods for human consumption

(A) P-1, Q-2, R-3, S-4
(B) P-2, Q-1, R-4, S-3
(C) P-1, Q-3, R-2, S-4
(D) P-3, Q-1, R-4, S-2

2004

267. Which apex body in India holds the statutory authority to approve the commercial release of a transgenic crop?

(A) Indian Council of Agricultural Research (ICAR)
(B) Department of Biotechnology (DBT)
(C) Review Committee on Genetic Manipulation (RCGM)
(D) Genetic Engineering Appraisal Committee (GEAC)

NODIA

2017

268. The Cartagena Protocol is an international agreement designed to ensure the safe handling, transport, and use of what?

(A) Nuclear waste
(B) Endangered species
(C) Synthetic pesticides
(D) Living Modified Organisms (LMOs)

2003

269. What is the primary purpose of conducting confined field trials for GM crops?

(A) To sell the harvest in the open market
(B) To distribute seeds to local farmers
(C) To evaluate the agronomic performance and biosafety under restricted environmental

2019

226. Bromoxynil resistance is engineered into crops using the bxn gene derived from Klebsiella ozaenae. What type of enzyme does this gene encode?
(A) Nitrilase
(B) Acetyltransferase
(C) Kinase
(D) Oxidase

2025

227. What is a primary environmental concern associated with the widespread use of herbicide-tolerant transgenic crops?
(A) Eradication of all soil bacteria
(B) Increased toxicity to non-target insect species
(C) The emergence of herbicide-resistant "superweeds"
(D) Depletion of atmospheric ozone

2015

228. The introduction of the modified EPSPS gene requires targeting the engineered protein to which subcellular organelle where the shikimate pathway occurs?
(A) Mitochondrion
(B) Endoplasmic reticulum
(C) Nucleus
(D) Chloroplast

2017

229. Osmoprotectants are small, highly soluble molecules engineered into plants to alleviate which type of stress?
(A) Pathogen infection
(B) Herbicide application
(C) Drought and salinity stress
(D) Heavy metal toxicity

2022

230. Arrange the following plant responses to drought stress in the correct sequence:
1. Increase in ABA concentration
2. Perception of soil water deficit
3. Stomatal closure
4. Reduction in transpiration rate

Which of the following represents the correct sequence?
(A) 2, 1, 3, 4
(B) 1, 2, 4, 3
(C) 2, 3, 1, 4
(D) 3, 4, 2, 1

2017

231. Proline and glycine betaine are examples of which class of stress-tolerance molecules?
(A) Phytoalexins
(B) PR proteins
(C) Osmoprotectants (compatible solutes)
(D) Herbicides

2014

232. Late Embryogenesis Abundant (LEA) proteins function primarily by what mechanism during abiotic stress?
(A) Acting as transcription factors
(B) Pumping sodium ions out of the cell
(C) Synthesizing ABA
(D) Protecting cellular structures and proteins from desiccation damage

2008

233. Trehalose overproduction in transgenic plants enhances tolerance to which specific stresses?
(A) Drought and cold
(B) Heat and viral infection
(C) Herbicide and fungal infection
(D) Flooding and darkness

2011

234. Transgenic expression of the NHX1 gene improves salinity tolerance by facilitating what cellular process?
(A) Vacuolar sodium compartmentalization
(B) Exclusion of ions from the root system
(C) Enzymatic degradation of sodium ions
(D) Synthesis of potassium ion concentrations

2004

235. The SOS (Salt Overly Sensitive) pathway governs ion homeostasis in plants. SOS1 encodes which specific transport protein?
(A) Vacuolar Na+/H+ antiporter
(B) Potassium channel
(C) Plasma membrane Na+/H+ antiporter
(D) Calcium pump

2004

236. Cold stress tolerance involves the expression of CBF/DREB transcription factors. What do these factors bind to?
(A) Ribosomes to halt translation
(B) The promoter regions of cold-responsive (COR) genes
(C) Introns of structural genes
(D) Chloroplast DNA directly

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strategies for fungal resistance?
(A) I, II and III
(B) I, II and IV
(C) II, III and IV
(D) I, III and IV

2009

216. Phytoalexins, targeted for up-regulation in transgenic plants, are best described as:
(A) Low molecular weight antimicrobial secondary metabolites
(B) Small RNA molecules
(C) Large PR proteins
(D) Structural cell wall components

2007

217. The herbicide glyphosate acts by competitively inhibiting which specific enzyme in plants?
(A) Acetolactate synthase (ALS) enzyme
(B) Glutamine synthetase (GS) enzyme
(C) EPSPS enzyme in the shikimate path
(D) Protoporphyrinogen oxidase (PPO)

2008

218. Consider the following statements on herbicide resistance mechanisms:
I. Target site mutation prevents herbicide binding.
II. Target overproduction titrates the herbicide.
III. Metabolic detoxification breaks down the herbicide.
IV. EPSPS engineering relies on metabolic detoxification.
V. The bar gene relies on metabolic detoxification.
Which of the above statement(s) is/are correct?
(A) I, II, III and V
(B) I, III, IV and V
(C) II, III, IV and V
(D) I, II, IV and V

2024

219. The CP4 EPSPS gene, utilized to create Roundup Ready crops, was originally isolated from which organism?
(A) Bacillus thuringiensis
(B) Escherichia coli
(C) Agrobacterium sp. strain CP4
(D) Arabidopsis thaliana

2005

220. Glufosinate (Phosphinothricin) inhibits glutamine synthetase, leading to a toxic cellular accumulation of which molecule?
(A) Shikimic acid
(B) Oxygen radicals
(C) Nitrite
(D) Ammonia

2019

221. The bar and pat genes confer resistance to glufosinate by encoding an enzyme that performs what chemical modification?
(A) Methylation of the herbicide
(B) Hydrolysis of the herbicide
(C) Acetylation of the herbicide
(D) Phosphorylation of the herbicide

2009

222. The shikimate pathway, targeted by glyphosate, is responsible for the biosynthesis of which class of compounds?
(A) Branched-chain amino acids
(B) Saturated fatty acids
(C) Purine nucleotides
(D) Aromatic amino acids

2014

223. Why is engineering resistance to glyphosate considered highly effective and safe for agricultural use?
(A) Glyphosate degrades into highly toxic persistent compounds in soil.
(B) The engineered plants metabolize glyphosate into fertilizer.
(C) The shikimate pathway is absent in mammals.
(D) Glyphosate is a natural plant hormone.

2023

224. Which enzyme is targeted by sulfonylurea and imidazolinone herbicides?
(A) EPSPS
(B) ACCase
(C) Rubisco
(D) Acetolactate synthase (ALS)

NODIA

2006

225. Consider the following genes and their resistance profiles:
I. CP4 EPSPS - Glyphosate
II. bar - Glufosinate
III. pat - Glufosinate
IV. bxn - Bromoxynil
V. ALS mutant - Paraquat
Which of the above accurately identifies correct gene-herbicide resistance pairs?
(A) I, II, III and IV
(B) I, II, IV and V
(C) II, III, IV and V
(D) I, III, IV and V

(B) Protease
(C) Amylase
(D) Lipase

2009

249. Which gene was expressed in Golden Rice to direct the synthesized precursor into the lycopene pathway?
(A) Phytoene desaturase
(B) Lycopene beta-cyclase
(C) Chalcone synthase
(D) Nitrate reductase

2010

250. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : Biofortification via genetic engineering is a sustainable approach to combat micronutrient malnutrition.
Reason (R) : It requires continuous and expensive dietary supplements to be effective.
(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2022

251. Amaranth seed albumin (AmA1) has been expressed in transgenic potatoes to significantly increase the levels of what?
(A) Starch
(B) Vitamin C
(C) Iron
(D) Essential amino acids

2014

252. The 'purple tomato' was genetically engineered to accumulate high levels of which health-promoting compounds?
(A) Beta-carotene
(B) Anthocyanins
(C) Glucosinolates
(D) Ascorbate peroxidase (APX)

2025

253. The Flavr Savr tomato, the first commercialized genetically modified food, was engineered for what specific post-harvest trait?
(A) Increased sweetness
(B) Resistance to bruising
(C) Delayed ripening and softening
(D) Enhanced color

2004

254. Flavr Savr utilized antisense technology to inhibit the expression of which cell wall-degrading enzyme?
(A) Cellulase
(B) Pectin methylesterase
(C) Xylanase
(D) Polygalacturonase

2025

255. Ethylene regulates fruit ripening. Which enzyme is the rate-limiting step in ethylene biosynthesis and a common target for delaying ripening?
(A) ACC synthase
(B) ACC oxidase
(C) Polygalacturonase
(D) Lipoxygenase

2009

256. Suppressing ACC oxidase activity in transgenic plants results in which physiological outcome?
(A) Accelerated leaf senescence
(B) Delayed fruit ripening and extended shelf life
(C) Increased seed dormancy
(D) Stunted plant growth

2025

257. Genetic modification of oil quality in crops like soybean often aims to increase the proportion of which fatty acid for improved health benefits and oxidative stability?
(A) Palmitic acid
(B) Oleic acid
(C) Stearic acid
(D) Linolenic acid

NODIA

2008

258. To achieve high oleic acid content in transgenic soybeans, RNAi is used to silence which specific enzyme?
(A) FAD2 (fatty acid desaturase 2)
(B) ACCase
(C) EPSPS
(D) Phytase

2023

259. The 'Arctic Apple' is engineered to resist enzymatic browning when sliced by silencing the genes encoding which enzyme?
(A) Phenylalanine ammonia-lyase (PAL)
(B) Ascorbate peroxidase (APX)
(C) Polyphenol oxidase (PPO)
(D) Catalase

is administered by which international organization?
(A) World Trade Organization (WTO)
(B) World Health Organization (WHO)
(C) United Nations (UN)
(D) Food and Agriculture Organization (FAO)

2023

281. Biopiracy refers to which controversial practice?
(A) Legal sharing of open-source seed sets
(B) Extraction of DNA in laboratory settings
(C) Commercialization without fair compensation
(D) Preservation of biodiversity in gene banks

2013

282. Which of the following cannot be patented under the Indian Patent Act (1970)?
(A) A naturally occurring plant variety or seed
(B) A novel process for synthesizing an agrochemical
(C) A genetically engineered microorganism
(D) A new agricultural implement

2012

283. The controversial patent granted on the wound-healing properties of which Indian plant was successfully revoked after a legal challenge establishing prior art?
(A) Tulsi (Ocimum tenuiflorum)
(B) Turmeric (Curcuma longa)
(C) Ashwagandha
(D) Neem (Azadirachta indica)

2018

284. A 'Utility Patent' is typically granted for a period of how many years from the filing date?
(A) 10 years
(B) 20 years
(C) 50 years
(D) Indefinitely

2012

285. In the context of patents, 'Prior Art' refers to what information?
(A) The aesthetic design of the product
(B) The future predicted uses of the invention
(C) All information made available to the public before a given effective date
(D) The secret proprietary notes of the inventor

2007

286. Match the IPR tool in List I with its primary subject of protection in List II:
List I : (IPR Tool)
P. Patent
Q. Copyright
R. Trademark
S. Geographical Indication
List II : (Subject of Protection)
1. Literary or artistic works
2. Inventions and novel processes
3. Goods originating from a specific territory possessing distinct qualities
4. Brand names and logos
(A) P-2, Q-1, R-4, S-3
(B) P-1, Q-2, R-3, S-4
(C) P-2, Q-4, R-1, S-3
(D) P-3, Q-1, R-2, S-4

2009

287. The term 'Sui Generis' in intellectual property means a system that is:
(A) Specifically designed for unique subjects
(B) Universally applicable to all world nations
(C) Exempt from international legal enforcement
(D) Based solely on existing copyright law frameworks

2021

288. The Convention on Biological Diversity (CBD) emphasizes which core principle regarding genetic resources?
(A) Open and unrestricted access to all resources
(B) Complete ban on international transfer of biological materials
(C) Mandatory patenting of all wild plant species
(D) Sovereign rights of nations over their biological resources and equitable benefit sharing

2015

289. Plant Breeders' Rights (PBR) grant the breeder of a new plant variety exclusive control over what?
(A) Exclusive control over propagating material
(B) Consumption of the harvested crop material
(C) Traditional farming practices of the region
(D) Soil where the plant variety is grown

2013

290. The following question consists of two statements — Assertion (A) and Reason (R). Answer the question by selecting the appropriate option.
Assertion (A) : The PPV&FR Act of India is unique globally because it simultaneously protects breeders, researchers, and farmers.
Reason (R) : It grants farmers the right to save, use, sow, resow, exchange, share or sell their farm produce, including seeds of a registered variety.
(A) Both A and R are true and R is the correct

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conditions
(D) To bypass laboratory safety testing

2005

270. Risk assessment of a transgenic crop typically includes evaluating its potential to become what in the natural environment?
(A) A nutrient
(B) A weed
(C) A biofertilizer
(D) A promoter

2009

271. Gene flow, a major environmental biosafety concern, refers to the unintended transfer of transgenes to which entities?
(A) Pollen flow to wild relatives or non-GM crops
(B) Transfer of transgenes into soil bacteria only
(C) The health of humans consuming the GM crop
(D) The insects feeding on the transgenic plant tissue

2019

272. Allergenicity assessment of a novel transgenic protein involves comparing its amino acid sequence to what database?
(A) Known toxic heavy metals
(B) Plant promoters
(C) Essential amino acids
(D) Known established allergens

2010

273. The RCGM functions under which Indian government ministry?
(A) Ministry of Environment, Forest and Climate Change
(B) Ministry of Science and Technology (DBT)
(C) Ministry of Agriculture and Farmers Welfare
(D) Ministry of Health and Family Welfare

2018

274. In biosafety terminology, 'substantial equivalence' is a concept used to establish what?
(A) That a GM crop is as safe and nutritious as its conventional counterpart
(B) That a GM crop is exactly identical in every DNA sequence to a non-GM crop
(C) That a GM crop has the same yield as a non-GM crop
(D) That a GM crop requires the same amount of water

2023

275. An Institutional Biosafety Committee (IBSC) is mandatory for any organization involved in recombinant DNA research. Who must be included in its constitution?
(A) Only scientists from the institution
(B) A representative from the World Health Organization
(C) An external nominee from the DBT
(D) Local farmers

2002

276. Which transgenic crop was the first to be legally approved for commercial cultivation in India?
(A) Bt Brinjal
(B) GM Mustard
(C) Golden Rice
(D) Bt Cotton

NODIA

2019

277. Intellectual Property Rights (IPR) are legal rights granted to inventors or creators to protect what?
(A) Physical land ownership
(B) Genetic resources in the public domain
(C) Creations of the mind, such as inventions and designs
(D) Basic human rights

2005

278. Arrange the following steps of the patent application process in the correct order:
1. Filing of patent application
2. Publication of application
3. Examination by patent office
4. Grant of patent

Which of the following represents the correct sequence?
(A) 1, 2, 3, 4
(B) 1, 3, 2, 4
(C) 2, 1, 3, 4
(D) 3, 1, 2, 4

2014

279. To be patentable, an invention must satisfy three fundamental criteria: novelty, industrial applicability, and what else?
(A) Affordability
(B) Complexity
(C) Profitability
(D) Non-obviousness (inventive step)

2018

280. The TRIPS Agreement, which establishes minimum standards for IPR regulation,

ANSWERS

1. (B) Totipotency
Totipotency refers to the remarkable capacity of a single nucleated plant cell to divide and regenerate into a whole plant. This biological phenomenon forms the fundamental basis for plant tissue culture and biotechnology. It occurs when differentiated somatic cells undergo metabolic changes, reverting to a meristematic state capable of generating any specialized cell type within the mature organism.

2. (A) Dedifferentiation
Dedifferentiation is the biological process where mature, specialized plant cells revert to a generalized, meristematic state. This transition allows cells that have already performed specific functions to regain their division potential. Once triggered by exogenous hormones, these cells lose their previous specialization and form an unorganized mass of cells known as a callus, facilitating regenerative growth.

3. (C) Redifferentiation
Redifferentiation occurs when unspecialized callus cells, previously derived through dedifferentiation, begin to develop into specific tissues or organs like roots and shoots. This step is essential for organogenesis and somatic embryogenesis in tissue culture. It represents the final stage where cells acquire new specialized functions, eventually leading to the formation of a complete, functional regenerated plant structure.

4. (A) I and II
Cellular totipotency relies on the genetic potential stored within the nucleus and requires appropriate exogenous stimuli to be expressed. While every nucleated plant cell possesses the necessary genetic information, specific environmental factors and hormonal concentrations are essential to trigger division and regeneration. This biological capability is a unique characteristic of plant cells, whereas animal cells typically exhibit limited potency.

5. (C) To serve as the initial tissue source
An explant serves as the starting tissue source used to initiate a plant tissue culture. It can be any part of the plant, such as a leaf, stem, or root segment, that is excised and placed on a nutrient medium. The successful regeneration of a whole plant depends on the selection, sterilization, and inherent regenerative capacity of this initial tissue source.

6. (A) P-3, Q-4, R-1, S-2
Dedifferentiation leads to the formation of callus from specialized tissues, while redifferentiation refers to organogenesis where callus develops into specific organs. Plasmolysis describes the shrinkage of cell contents due to water loss in hypertonic environments. Totipotency is the unique biological property allowing a single cell to regenerate into a whole plant. These processes are fundamental to plant biotechnology.

7. (D) Retention of the complete genome
The ability of a somatic plant cell to express totipotency is fundamentally dependent on the retention of its complete and functional genome. Even after specialization, the cell maintains the full genetic blueprint required for all developmental stages. This genetic integrity allows the cell to be reprogrammed under specific hormonal conditions, enabling the regeneration of all tissues and organs.

8. (A) Carrot phloem
The first conclusive evidence of cellular totipotency was provided through the successful culture of carrot phloem tissue. Researchers demonstrated that individual cells from the carrot root could be induced to divide and eventually regenerate into entire, fertile plants. This groundbreaking discovery validated the concept that specialized somatic plant cells retain the genetic information necessary for full organism development.

9. (C) It is an irreversible process leading to cell death.
Dedifferentiation is a reversible biological process that allows specialized cells to reenter the cell cycle and form a callus. It does not lead to cell death; instead, it restores the capacity for division and growth. During this phase, cells lose their previous specialized functions and undergo

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explanation of A.
(B) Both A and R are true but R is not the correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

2011

291. To be registered under the PPV&FR Act, a new plant variety must fulfill the criteria of DUS. What does DUS stand for?
(A) Diversity, Utility, and Safety
(B) Disease-resistance, Uniformity, and Seed-yield
(C) Distinctiveness, Uniformity, and Stability
(D) Distinctiveness, Utility, and Sovereignty

2004

292. Under the UPOV Convention, what is the 'Breeders' Exemption'?
(A) Breeders are exempt from paying taxes on seed sales.
(B) Breeders are exempt from biosafety regulations.
(C) Breeders can legally patent natural genes.
(D) Breeders can freely use a protected variety as an initial source of variation for creating other new varieties.

2016

293. In India, the Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act was enacted in which year?
(A) 1970
(B) 1995
(C) 2001
(D) 2010

2014

294. What specific restriction does the PPV&FR Act place on a farmer regarding the sale of protected seeds?
(A) A farmer cannot save seeds for the next season.
(B) A farmer cannot sell the seed under the brand name of the registered breeder.
(C) A farmer cannot exchange seeds with neighbors.
(D) A farmer must pay a royalty for personal use.

2005

295. Extant varieties, which can be registered under the PPV&FR Act, include varieties that are:
(A) Extinct and found only in fossils
(B) Exclusively produced through genetic engineering
(C) Already available in the market or are farmers' varieties
(D) Imported illegally

2005

296. The concept of "essentially derived varieties" (EDV) was introduced in UPOV 1991 to protect original breeders against what practice?
(A) Minor genetic changes to a protected variety
(B) Misuse of indigenous tribal knowledge
(C) Free exchange of seeds among small farmers
(D) Cultivation of local open-pollinated varieties

2004

297. Which fund is constituted under the PPV&FR Act to support the conservation of genetic resources by farming communities?
(A) National Gene Fund
(B) National Biodiversity Fund
(C) Gene Campaign Trust
(D) Farmers' Royalty Account

NODIA

2004

298. Identify the INCORRECT statement regarding the PPV&FR Act in India.
(A) It strictly prohibits farmers from saving seeds of a registered variety.
(B) It provides protection for new plant varieties.
(C) It allows researchers to use registered varieties for experiments.
(D) It requires payment of an annual fee to maintain registration.

2013

299. Under the PPV&FR Act, what is the maximum duration of protection granted for trees and vines?
(A) 10 years
(B) 15 years
(C) 18 years
(D) 20 years

2005

300. The right of a community to claim compensation for their contribution to the evolution of a registered plant variety is known as what?
(A) Patent Right
(B) Benefit Sharing
(C) Trade Secret
(D) Compulsory Licensing

****

2001

237. Which osmolyte is synthesized via the action of the enzymes choline monooxygenase (CMO) and betaine aldehyde dehydrogenase (BADH)?
(A) Glycine betaine
(B) Proline
(C) Mannitol
(D) Trehalose

2023

238. Identify the INCORRECT statement concerning plant responses to abiotic stress.
(A) Reactive Oxygen Species (ROS) generation increases during stress.
(B) Compatible solutes interfere significantly with normal cellular metabolism.
(C) Antioxidant enzymes like SOD and APX are up-regulated to scavenge ROS.
(D) Transgenic expression of transcription factors can activate multiple stress-tolerance genes simultaneously.

2025

239. The engineered overproduction of mannitol in plants provides protection against osmotic stress and which other damaging agent?
(A) Scavenge reactive oxygen species
(B) Neutralize fungal toxins
(C) Block ultraviolet light
(D) Replicate RNA viruses

2017

240. Select the correct sequence for engineering an ion transporter for salt tolerance:
(A) Identify transporter gene, Clone into expression vector, Transform plant, Evaluate salinity tolerance
(B) Evaluate salinity tolerance, Clone into expression vector, Transform plant, Identify transporter gene
(C) Transform plant, Identify transporter gene, Evaluate salinity tolerance, Clone into expression vector
(D) Clone into expression vector, Evaluate salinity tolerance, Identify transporter gene, Transform plant

2025

241. Golden Rice was genetically engineered to combat a deficiency in which essential nutrient?
(A) Iron
(B) Vitamin A
(C) Vitamin C
(D) Calcium

2007

242. The endosperm of wild-type rice lacks which key compound required for Vitamin A synthesis?
(A) Beta-carotene
(B) Phytic acid
(C) Anthocyanin
(D) Ferritin

2006

243. The original Golden Rice prototype incorporated the phytoene synthase (psy) gene derived from which plant?
(A) Carrot
(B) Maize
(C) Daffodil (Narcissus pseudonarcissus)
(D) Tomato

2012

244. To complete the beta-carotene biosynthetic pathway in Golden Rice, the crtI gene was introduced from which organism?
(A) Saccharomyces cerevisiae (yeast)
(B) Arabidopsis thaliana (plant)
(C) Agrobacterium tumefaciens (bacteria)
(D) Erwinia uredovora (bacteria)

2006

245. Golden Rice 2 achieved significantly higher beta-carotene levels by substituting the daffodil psy gene with the psy gene from which plant?
(A) Wheat (Triticum aestivum)
(B) Carrot (Daucus carota)
(C) Maize (Zea mays)
(D) Sweet potato (Ipomoea batatas)

2010

246. Iron biofortification in rice aims to address anemia. A common strategy involves expressing which iron-storage protein?
(A) Hemoglobin
(B) Ferritin
(C) Transferrin
(D) Metallothionein

2010

247. Phytic acid in seeds negatively impacts nutritional quality by performing what action?
(A) Enhancing vitamin degradation rates
(B) Causing specific allergic reactions
(C) Promoting the growth of seed fungi
(D) Chelating essential dietary minerals

2022

248. Transgenic approaches to reduce phytic acid levels often involve expressing which enzyme to break it down?
(A) Phytase

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metabolic reprogramming, which is crucial for subsequent redifferentiation into new plant organs.

10. (C) A is true but R is false.
Callus tissue consists of an unorganized, proliferating mass of parenchymatous cells formed from an explant. This mass develops during dedifferentiation, when specialized cells revert to an unspecialized meristematic state. Redifferentiation is the subsequent process where these callus cells acquire specialized functions to form organs. Therefore, callus results from dedifferentiation rather than redifferentiation, making the provided reason scientifically inaccurate.

11. (D) Parenchyma
Parenchyma cells are the most responsive cell type for dedifferentiation because they are relatively unspecialized and maintain their metabolic activity. These cells can easily be triggered to reenter the cell cycle when exposed to specific plant growth regulators. In contrast, highly specialized or lignified cells like sclerenchyma and tracheids have lost the flexibility needed to revert to a meristematic state.

12. (B) Plant growth regulators
Habituation is a phenomenon where cultured plant tissues gradually lose their requirement for exogenous plant growth regulators, such as auxins or cytokinins. Over time, the cells acquire the ability to synthesize these hormones internally at levels sufficient to maintain growth and division. This autonomous growth capacity indicates a significant metabolic shift within the cultured cells during prolonged in vitro cultivation.

13. (C) Ammonium nitrate
Ammonium nitrate serves as the primary and most efficient source of inorganic nitrogen in Murashige and Skoog media. It provides nitrogen in both ammonium and nitrate forms, which are essential for synthesizing proteins, nucleic acids, and other vital cellular components. This dual nitrogen source helps maintain pH stability in the medium and supports rapid growth and differentiation during tissue culture.

14. (D) Sucrose
Sucrose is the most widely utilized carbon and energy source in plant tissue culture media. It serves as an essential carbohydrate for cellular respiration and provides the osmotic potential necessary for nutrient uptake. Most plant tissues can easily hydrolyze sucrose into glucose and fructose, which are then used for metabolic processes, supporting the growth and development of the cultured explants.

15. (C) III and IV
Gibberellins are primarily used for stem elongation and embryo germination, rather than being the main driver for somatic embryogenesis. Furthermore, a high auxin to cytokinin ratio typically promotes root initiation, whereas a low ratio favors shoot development. Therefore, the statements regarding the primary use of gibberellins and the effects of hormone ratios on shoot development are biologically incorrect.

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16. (B) Callus formation
The combination of a strong auxin like 2,4-D and a cytokinin like Kinetin is standard for inducing callus formation in many plant species. Auxins stimulate DNA replication and cell division, while cytokinins promote the progression of the cell cycle. This synergistic hormonal balance prevents the immediate formation of organs, instead favoring the proliferation of an unorganized mass of cells.

17. (B) Thiamine
Thiamine, also known as Vitamin B1, is considered an essential component in almost all plant tissue culture media. It acts as a vital cofactor for several key enzymes involved in carbohydrate metabolism and the citric acid cycle. While plants can synthesize thiamine, the levels produced by isolated tissues in vitro are often insufficient, necessitating exogenous supplementation to ensure healthy growth.

18. (A) Acts as a solidifying agent
Agar is a polysaccharide derived from seaweed used primarily as a solidifying agent in plant tissue culture media. It provides a stable surface for explant placement and allows for the uniform diffusion of nutrients and hormones to the tissue. Agar is preferred because it remains solid at incubation temperatures, is chemically inert, and is not degraded by plant enzymes during culture.

19. (C) Zeatin : Cell division
Zeatin is a naturally occurring cytokinin that plays a fundamental role in promoting cell division and shoot formation in plant tissues.

93. (A) Add restriction sites to DNA fragments
Adaptors and linkers are short, synthetic double-stranded DNA molecules used in library construction to add specific restriction sites to the ends of DNA fragments. This is particularly useful when the fragments were generated by shearing or have ends that are incompatible with the cloning vector. By providing compatible cohesive ends, these molecules facilitate efficient and targeted ligation of the insert into the vector.

94. (B) Antibodies
Expression libraries are typically screened using specific antibodies that recognize the protein product of the inserted gene. In these libraries, the cloned DNA is transcribed and translated by the host cell. By using a labeled antibody as a probe, researchers can detect which bacterial colonies are producing the desired protein, enabling the identification of the corresponding gene from the library.

95. (B) Different tissues express different sets of mRNA.
cDNA libraries are tissue-specific because different tissues express distinct sets of messenger RNA (mRNA) at any given time. While all cells in an organism contain the same genomic DNA, gene expression is highly regulated, resulting in unique transcriptomes. Consequently, a cDNA library made from leaf tissue will contain a different collection of clones than one made from root or floral tissue.

96. (B) Generation of overlapping DNA fragments
Partial digestion of genomic DNA during library construction is used to ensure the generation of a set of overlapping DNA fragments. By limiting the action of restriction enzymes, some target sites remain uncut, creating larger pieces that span across different genes. These overlaps are essential for chromosome walking and for assembling a continuous physical map of the genome from individual cloned fragments.

97. (B) Regulate the transcription of genes
In plant genetic engineering, a promoter is a specific DNA sequence located upstream of a gene that regulates its transcription. It serves as the binding site for RNA polymerase and other transcription factors, determining when, where, and at what level a gene is expressed. By selecting different types of promoters, researchers can precisely control the production of recombinant proteins in transgenic plants.

98. (A) I and II
Constitutive promoters, such as the Cauliflower Mosaic Virus (CaMV) 35S promoter, are designed to drive continuous and high-level gene expression across almost all tissues and developmental stages of a plant. Unlike inducible or tissue-specific promoters, they do not require environmental or developmental triggers. These promoters are essential tools in plant biotechnology for ensuring the steady production of desired traits throughout the plant.

99. (C) RolD promoter
The rolD promoter, derived from Agrobacterium rhizogenes, is a classic example of a tissue-specific promoter that drives gene expression primarily in the roots. Using such a promoter is ideal for targeting traits like nutrient uptake or resistance to soil-borne pathogens specifically to the root system. This avoids the unnecessary metabolic drain associated with expressing the transgene in every tissue of the plant.

100. (D) Respond to specific endogenous or exogenous stimuli
Inducible promoters are regulatory DNA sequences that activate gene expression only in response to specific endogenous or exogenous stimuli. These triggers can include environmental factors like heat, drought, or light, as well as chemical applications. This provides researchers with precise temporal and spatial control over transgene expression, allowing the plant to produce specific proteins only when they are most needed.

101. (A) Seeds
The napin promoter is a tissue-specific promoter derived from Brassica species that is commonly used to drive high-level gene expression exclusively in the developing seeds. This makes it a valuable tool for modifying seed-specific traits, such as oil composition, protein content, or the production of therapeutic molecules. By restricting expression to the seed, researchers minimize any potential negative effects on other tissues.

102. (B) Cauliflower mosaic virus
The CaMV 35S promoter is a powerful constitutive promoter originally isolated from the

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gamete with two polar nuclei. Culturing this tissue in vitro allows for the regeneration of triploid plants, which are often valued for their seedlessness in crops.

29. (C) Prolonged callus phase and high PGR levels
Somaclonal variation occurs primarily due to the genetic and epigenetic changes that accumulate during the prolonged callus phase of tissue culture. The high concentrations of plant growth regulators used to induce and maintain callus can trigger chromosomal rearrangements, point mutations, and DNA methylation changes. These alterations result in regenerated plants that exhibit different phenotypic and genotypic characteristics from the original donor.

30. (A) Anther inoculation, Callus induction, Haploid regeneration, Chromosome doubling
Developing a homozygous fertile line via anther culture begins with the inoculation of immature anthers on a culture medium. This is followed by the induction of callus from microspores and the subsequent regeneration of haploid plantlets. Finally, chemical treatment with agents like colchicine is applied for chromosome doubling, which restores fertility and achieves complete homozygosity in the resulting regenerated plant population.

31. (A) Appical meristem
The apical meristem is specifically used as an explant to produce virus-free plants through meristem culture. This tissue is typically devoid of viruses because it lacks a vascular connection and possesses high metabolic activity and rapid cell division that outpaces viral replication. By regenerating whole plants from this small region, researchers can eliminate systemic viral infections and produce healthy foundation stock.

32. (B) Monoploid/Haploid
Plants regenerated directly from microspores possess a monoploid or haploid ploidy level because they originate from male gametophytic cells. These cells have already undergone meiosis, resulting in a single set of chromosomes. Such haploid plants are extremely valuable in plant breeding for detecting recessive mutations and can be converted into fertile, homozygous double haploids through chromosome doubling techniques using chemical treatments.

33. (B) Unfertilized ovary
Gynogenesis is the in vitro process used to produce haploid plants from female gametophytic tissues, specifically the unfertilized ovary or ovule. This technique is an alternative to anther culture and is particularly useful in species where androgenesis is inefficient. The resulting plants are haploid and contain only the maternal set of chromosomes, providing a valuable tool for genetic mapping and breeding programs.

34. (A) Somaclonal variation
Somaclonal variation describes the phenomenon where off-types or genetic variants arise from vegetatively propagated in vitro cultures. While tissue culture is often intended for clonal propagation, the stress of the environment and the callus phase can induce mutations. These variations can be morphological, physiological, or biochemical and may be either stable and heritable or transient, offering a source of new genetic diversity.

35. (C) Homozygosity
The primary advantage of double haploid technology is the rapid achievement of complete homozygosity in just one generation. In conventional breeding, reaching this state requires multiple rounds of selfing over several years. By doubling the chromosomes of a haploid, every gene locus becomes homozygous, allowing breeders to immediately evaluate and fix desirable traits, significantly accelerating the development of new plant varieties.

36. (D) Endosperm degeneration
In many interspecific crosses, the primary structural barrier to successful hybrid production is endosperm degeneration. While the zygote may form correctly, the endosperm fails to develop properly, depriving the embryo of necessary nutrients and leading to its abortion. Embryo rescue bypasses this barrier by providing the immature embryo with a synthetic nutrient medium that replaces the function of the failing natural endosperm.

37. (C) -196 degrees C
Standard cryopreservation for long-term storage occurs at -196 degrees Celsius, which is the boiling point of liquid nitrogen. At this extremely low temperature, all metabolic processes and chemical reactions within the plant cells are virtually arrested. This allows the

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biological material to be preserved for indefinite periods without genetic deterioration, making it a critical technique for the conservation of plant germplasm.

38. (B) Pre-treatment, Freezing, Storage, Thawing
Standard cryopreservation involves a specific sequence starting with the pre-treatment of tissues with cryoprotectants to prevent ice damage. This is followed by freezing at a controlled rate or through vitrification. Once frozen, the samples are placed in long-term storage in liquid nitrogen. Finally, when needed, the tissues undergo rapid thawing to restore metabolic activity while preventing the formation of lethal ice crystals.

39. (D) Arrest of all internal metabolic activities
The fundamental principle of cryopreservation is the total arrest of internal metabolic activities and biochemical reactions within the tissue. By storing plant material at ultra-low temperatures, usually in liquid nitrogen, cellular time is effectively stopped. This prevents aging, genetic drift, and the accumulation of mutations, ensuring that the germplasm remains genetically stable and viable for extremely long durations during storage.

40. (A) 2, 1, 3, 4
The vitrification process begins with the careful excision of the explant, followed by dehydration using concentrated cryoprotectant solutions. Once dehydrated, the tissue is plunged directly into liquid nitrogen to achieve a glass-like state without ice crystal formation. After storage, the samples are recovered through rapid thawing in a warm water bath to maintain viability and prevent recrystallization damage during the transition.

41. (C) Dimethyl sulfoxide (DMSO)
Dimethyl sulfoxide (DMSO) is a universally used penetrating cryoprotectant in plant biotechnology. It functions by entering the cell and reducing the freezing point of the cytoplasm, which minimizes the formation of intracellular ice crystals. By protecting the integrity of the cell membrane and organelles during the freezing process, DMSO significantly enhances the survival rate of various plant tissues following cryopreservation.

42. (A) Amorphous glass
Vitrification in cryopreservation refers to the physical transition of water into an amorphous, glass-like state rather than crystalline ice. This is achieved through rapid cooling and the use of concentrated cryoprotectants. Because this solid state lacks the sharp structure of ice crystals, it prevents the physical rupture of cellular membranes and organelles, which is essential for maintaining the viability of tissues.

43. (D) Ice crystals physically rupture cellular membranes
Prevention of intracellular ice crystal formation is critical during cryopreservation because these crystals physically rupture and destroy delicate cellular membranes and organelles. The sharp edges of ice crystals cause irreversible mechanical damage, leading to the loss of cellular integrity and death upon thawing. Techniques like vitrification and the use of cryoprotectants are designed specifically to avoid this lethal crystalline phase during freezing.

44. (B) Inducing osmotic dehydration of the cell
Non-penetrating cryoprotectants, such as sucrose or polyethylene glycol, function primarily by inducing osmotic dehydration of the plant cells. By increasing the external osmotic pressure, they pull water out of the cytoplasm before freezing occurs. This reduction in internal water content decreases the likelihood of intracellular ice formation, thereby protecting the cell's internal structures and increasing its resilience to ultra-low temperatures.

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45. (C) 37 to 40 degrees C
Rapid thawing of cryopreserved plant tissues is typically conducted in a water bath set between 37 and 40 degrees Celsius. This specific temperature range is used to ensure a swift transition from the frozen state to a liquid state. Fast warming prevents the phenomenon of ice recrystallization, where small ice crystals merge into larger, damaging ones, which could otherwise kill the cells.

46. (D) Cryoprotectants are highly toxic and are never removed after thawing.
Cryoprotectants are essential for preventing ice damage during freezing, but they can be toxic at high concentrations. Therefore, it is a critical step in the cryopreservation protocol to remove these substances by washing the

tissues immediately after thawing. Failure to remove cryoprotectants would lead to chemical injury and cell death, preventing the successful recovery and subsequent growth of the preserved explants.

47. (A) Sucrose
Sucrose is a common non-penetrating cryoprotectant used in conjunction with penetrating agents like DMSO. It serves as an osmotic agent that helps dehydrate cells prior to freezing, reducing the amount of free water available to form ice. Additionally, sucrose helps stabilize the cell membranes and proteins during the extreme cold, contributing to higher recovery rates of tissues after the cryopreservation process.

48. (B) Cell viability
The TTC (Triphenyl tetrazolium chloride) assay is used post-cryopreservation to evaluate cell viability and respiratory activity. Living cells contain dehydrogenase enzymes that reduce the colorless TTC into a red-colored compound called formazan. The intensity of the red color provides a visual and quantifiable indication of the metabolic health and survival of the tissues, allowing researchers to assess the success of the cryopreservation.

49. (B) Cellulase and Pectinase
Plant protoplast isolation requires a combination of cellulase and pectinase enzymes to successfully remove the rigid cell wall. Pectinase breaks down the middle lamella that holds cells together, while cellulase digests the cellulose microfibrils of the primary cell wall. This enzymatic treatment leaves behind the naked protoplast, which is a cell bounded only by the plasma membrane, suitable for subsequent fusion experiments.

50. (A) Both A and R are true and R is the correct explanation of A.
Somatic hybridization is a powerful technique that allows for the crossing of sexually incompatible plant species by fusing their protoplasts. This method bypasses natural barriers such as pre-zygotic or post-zygotic incompatibility that prevent traditional fertilization. Because the process occurs at the cellular level in vitro, it enables the combination of genetic material from distant relatives, facilitating the creation of novel hybrids.

51. (C) Polyethylene glycol (PEG)
Polyethylene glycol (PEG) is the most extensively used chemical agent for inducing the fusion of plant protoplasts. It functions by acting as a molecular bridge that brings the negatively charged protoplast membranes into close proximity, causing them to adhere and eventually merge. This chemical method is relatively simple, highly effective, and widely applicable across many different plant species for somatic hybridization.

52. (D) Nucleus from one parent and cytoplasm from both parents
In somatic hybridization, a cybrid (cytoplasmic hybrid) is a cell that contains the nucleus of only one parent but the cytoplasm from both parents. This unique genetic configuration is achieved when the nucleus of one parent is lost or inactivated during the fusion process. Cybrids are particularly useful for transferring organelle-encoded traits, such as cytoplasmic male sterility, between different plant species.

53. (D) Electrofusion
Electrofusion is a sophisticated method used for the electrical fusion of protoplasts. It involves two main steps: first, an alternating current field is applied to align the protoplasts into "pearl chains." Subsequently, a high-intensity direct current pulse is delivered to induce transient pores in the membrane, leading to the fusion of adjacent cells. This technique offers higher precision and efficiency.

54. (B) Mannitol
Mannitol is an essential sugar alcohol used as an osmoticum during protoplast isolation and culture. Because protoplasts lack a rigid cell wall, they are extremely fragile and susceptible to bursting in hypotonic solutions. Mannitol maintains the necessary osmotic pressure to keep the cells intact and stable. It is preferred because it is generally metabolically inert and is not easily utilized by the cells.

55. (D) Partial or total loss of parental chromosomes
Asymmetric somatic hybrids are characterized by the partial or total loss of chromosomes from one of the parental species. Unlike symmetric hybrids which retain both full genomes, asymmetric hybrids result from the intentional or spontaneous elimination of genetic material during fusion or subsequent cell divisions. This

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technique is often used to transfer specific small segments of DNA or individual traits between distantly related species.

56. (A) Production of sterile or abnormal plants
A primary limitation of somatic hybridization is the frequent production of sterile or morphologically abnormal plants. When protoplasts from distantly related species are fused, the resulting hybrids often face genomic instability, chromosomal imbalances, and nucleo-cytoplasmic incompatibilities. These issues can prevent the hybrid from undergoing normal development or reproducing, limiting the direct agricultural application of many wide-cross somatic hybrids produced through this method.

57. (C) Auxotrophic complementation
Auxotrophic complementation is a selection system that identifies hybrid protoplasts based on their ability to grow in media where the parental cells cannot survive. Each parent possesses a different metabolic deficiency (auxotrophy) that prevents growth. However, the hybrid cell inherits the functional genes from both parents, allowing it to synthesize the missing nutrients and thrive, thereby enabling the isolation of fused cells.

58. (A) Nicotiana glauca and Nicotiana langsdorffii
The first successful interspecific somatic hybrid was produced between Nicotiana glauca and Nicotiana langsdorffii using protoplast fusion. This landmark achievement demonstrated that sexually incompatible species could be combined genetically in vitro. The resulting hybrid exhibited characteristics of both parents and validated somatic hybridization as a viable tool for plant improvement, paving the way for further research in wide-crossing and crop engineering.

59. (D) Cytoplasmic male sterility
Cybrids are especially valuable in plant breeding for the transfer of cytoplasmic male sterility (CMS), a trait controlled by the mitochondrial genome. Since cybrids combine the nuclear genome of one parent with the organelles of another, CMS can be introduced into elite lines without the need for multiple backcrosses. This accelerates the development of hybrid seed production systems in many important crops.

60. (B) To align the protoplasts into pearl chains
During the electrical fusion of protoplasts, the alternating current (AC) field is used to align the cells into linear arrangements known as "pearl chains." This alignment ensures that the protoplasts are in direct physical contact with one another. Once aligned, a subsequent high-voltage direct current pulse can then be applied to induce the actual membrane fusion at the contact points.

61. (C) Bacteriophage infections
Restriction endonucleases function naturally in bacteria as a primitive immune system to defend against bacteriophage infections. These enzymes recognize and cleave specific foreign DNA sequences introduced by invading viruses, effectively neutralizing them. To protect its own DNA from being digested, the host bacterium modifies its recognition sites through methylation, allowing the enzymes to distinguish between self and non-self genetic material.

62. (B) Type II
Type II restriction enzymes are the most commonly used class in recombinant DNA technology. Unlike Type I or Type III enzymes, they recognize specific palindromic sequences and cleave the DNA at precise, predictable locations within or very close to those sites. This consistency allows researchers to generate DNA fragments with known ends, which is essential for accurate gene cloning and mapping.

63. (C) 5'-GAATTC-3'
EcoRI is a widely used Type II restriction enzyme that recognizes the specific six-base pair palindromic sequence 5'-GAATTC-3'. It cleaves the sugar-phosphate backbone between the Guanine and Adenine bases on both strands. This staggered cut produces "sticky ends" with 5' overhanging sequences, which facilitate the ligation of DNA fragments with complementary ends from different sources during the cloning process.

64. (D) Phosphodiester bond
DNA ligase is an essential enzyme that catalyzes the formation of a covalent phosphodiester bond between the 3' hydroxyl group and the 5' phosphate group of adjacent nucleotides. This reaction joins DNA fragments together, effectively "pasting" the genetic material. In molecular cloning, ligase is used to seal the nicks

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between the insert DNA and the vector DNA, creating a continuous molecule.

65. (A) Self-ligation of the vector
Alkaline Phosphatase is used to treat linearized cloning vectors to prevent self-ligation. The enzyme removes the 5' phosphate groups required by DNA ligase to form a phosphodiester bond. Without these phosphates, the vector cannot recircularize with itself. This significantly increases the efficiency of cloning by ensuring that only vectors that have incorporated an insert, which provides the necessary phosphates, can ligate.

66. (A) P-4, Q-1, R-2, S-3
DNA Polymerase I synthesizes DNA from a DNA template, while Reverse Transcriptase creates DNA from an RNA template. Polynucleotide Kinase is responsible for adding phosphate groups to the 5' ends of DNA. Terminal Deoxynucleotidyl Transferase adds homopolymer tails to the 3' ends without a template. These enzymes are fundamental tools for manipulating and modifying DNA and RNA in recombinant DNA research.

67. (C) DNA Polymerase I
DNA Polymerase I is responsible for removing RNA primers from the 5' end of Okazaki fragments during DNA replication in E. coli. It utilizes its unique 5' to 3' exonuclease activity to degrade the RNA and simultaneously uses its polymerase activity to fill the resulting gaps with DNA nucleotides. This dual action ensures the creation of a continuous DNA strand.

68. (D) They recognize the same DNA sequence.
Isoschizomers are pairs of restriction enzymes isolated from different bacterial species that recognize the exact same DNA sequence. While they share the same target site, they may cleave the DNA at different positions within that site or have different sensitivities to DNA methylation. Researchers use isoschizomers to study methylation patterns or to provide flexibility in choosing reaction conditions for DNA digestion.

69. (C) 5'→3' polymerase and 3'→5' exonuclease
The Klenow fragment is a large proteolytic fragment of DNA polymerase I that retains 5'→3' DNA polymerase activity and 3'→5' exonuclease (proofreading) activity. However, it lacks the 5'→3' exonuclease activity present in the full-length enzyme. Because of its proofreading ability, the Klenow fragment is widely used for DNA end filling, second-strand synthesis, and preparation of labeled DNA probes in molecular biology.

70. (A) Both A and R are true and R is the correct explanation of A.
Restriction enzyme digestion often results in "sticky ends," which are short, single-stranded overhanging sequences of DNA. These ends are highly advantageous in cloning because they facilitate efficient ligation through complementary base pairing with other DNA fragments cut by the same enzyme. This specific pairing acts like a molecular guide, ensuring that the insert and vector align correctly before being permanently joined.

71. (D) Single-stranded DNA and RNA
S1 nuclease is an enzyme that specifically degrades single-stranded DNA and RNA into mono- or oligonucleotides. It does not act on double-stranded DNA or DNA-RNA hybrids under standard conditions. This specificity makes it a valuable tool in molecular biology for removing single-stranded tails from DNA fragments, mapping RNA transcripts, and analyzing the structure of DNA-RNA hybrids during various laboratory procedures.

72. (A) T4 Polynucleotide kinase
T4 Polynucleotide kinase is an enzyme used to transfer a phosphate group from ATP to the 5' hydroxyl terminus of a DNA or RNA molecule. This process is essential for labeling the 5' ends of nucleic acids with radioactive phosphorus or for preparing DNA fragments for ligation if they lack a 5' phosphate. It is a vital tool in molecular cloning.

73. (C) It enables independent replication within the host
The origin of replication (ori) is a fundamental feature of all cloning vectors that allows them to replicate independently of the host's chromosomal DNA. This sequence is recognized by the host cell's replication machinery, ensuring that the vector and its inserted gene are copied and maintained through successive cell divisions. The nature of the ori also dictates the vector's copy number.

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74. (A) Identify host cells containing the specific plasmid
Selectable markers, such as antibiotic resistance genes, are included in cloning vectors to identify host cells that have successfully taken up the plasmid. When bacteria are grown on a medium containing the antibiotic, only those carrying the vector will survive and form colonies. This process effectively filters out the vast majority of untransformed cells, ensuring that researchers work with positive clones.

75. (B) Bacterial Artificial Chromosome (BAC)
Bacterial Artificial Chromosomes (BACs) are specialized vectors designed to clone very large DNA fragments, typically ranging from 100 to 300 kilobases. They are based on the F-plasmid of E. coli and are maintained at a low copy number to ensure the stability of the large inserts. BACs are essential tools for large-scale genomic mapping and the construction of genomic libraries.

76. (B) lacZ'
The pUC series of plasmids contains a multiple cloning site (MCS) located within the lacZ' gene, which encodes the alpha-peptide of beta-galactosidase. This arrangement allows for blue-white screening of recombinant clones. When foreign DNA is inserted into the MCS, it disrupts the lacZ' gene, preventing the production of functional enzyme. Consequently, recombinant colonies appear white, while non-recombinant colonies turn blue.

77. (C) Phage lambda cos sites
Cosmids are hybrid cloning vectors that combine the high-capacity features of plasmids with the specific "cos" (cohesive end) sites from bacteriophage lambda. These cos sites allow the large recombinant DNA molecules to be packaged into viral particles for highly efficient delivery into E. coli cells. Once inside the host, cosmids replicate as circular plasmids, accommodating inserts of up to 45 kilobases.

78. (D) They are exclusively propagated in bacterial hosts.
Yeast Artificial Chromosomes (YACs) are sophisticated vectors designed to mimic natural yeast chromosomes. They contain essential functional elements such as a centromere, telomeres, and an autonomous replication sequence. While they can be initially manipulated in bacteria, YACs are specifically designed to be propagated and maintained within yeast hosts like Saccharomyces cerevisiae. This allows for the stable cloning of extremely large DNA fragments.

79. (B) 20 kb
Bacteriophage lambda replacement vectors are engineered to carry DNA inserts by replacing a non-essential central "stuffer" region of the viral genome. These vectors have a maximum insert capacity of approximately 20 kilobases. This size is dictated by the physical constraints of the phage head, which can only package DNA molecules that are roughly 80% to 105% of the wild-type genome size.

80. (A) P-1, Q-2, R-3, S-4
Plasmids typically carry small inserts up to 10 kb, while cosmids accommodate larger fragments up to 45 kb. BACs are used for much larger genomic pieces up to 300 kb, and YACs offer the highest capacity, reaching up to 1000 kb or more. Matching the vector to the insert size is a critical step in successfully constructing and screening DNA libraries.

81. (B) Escherichia coli
Bacterial Artificial Chromosomes (BACs) are primarily propagated within the common laboratory bacterium Escherichia coli. Despite being designed to carry very large DNA inserts, BACs are derived from the E. coli F-factor plasmid, which ensures they are maintained at a stable, low copy number of one to two per cell. This stability makes E. coli an ideal host for large-scale genomic sequencing projects.

82. (A) Tetracycline
In the plasmid pBR322, the BamHI restriction site is located within the gene that confers resistance to the antibiotic tetracycline. When a foreign DNA fragment is successfully inserted into this site, it disrupts the coding sequence of the gene, a process known as insertional inactivation. Consequently, the host bacteria lose their ability to survive in the presence of tetracycline during selection.

83. (C) Single-stranded phages
Phagemids are versatile cloning vectors that combine the features of a standard plasmid with an origin of replication from a single-stranded filamentous bacteriophage, such as M13. This

dual origin allows the vector to replicate as a double-stranded plasmid in E. coli or to be packaged as single-stranded DNA when the host is co-infected with a helper phage for sequencing.

84. (D) Centromere
The centromere (CEN) is a vital structural component of Yeast Artificial Chromosomes (YACs) that ensures the stable and accurate segregation of the vector during yeast cell division. It functions as the attachment site for spindle fibers, mimicking the behavior of natural chromosomes. Without a functional centromere, the YAC would be frequently lost, leading to instability of the large DNA inserts.

85. (A) Coding and non-coding genomic regions
A genomic DNA library provides a comprehensive representation of an organism's entire genome. It contains clones representing both the coding sequences (exons) and the non-coding regions, such as introns, promoters, and intergenic spaces. This type of library is essential for studying gene structure, identifying regulatory elements, and conducting whole-genome sequencing projects, as it captures the complete genetic blueprint of the organism.

86. (B) Reverse transcriptase
Reverse transcriptase is an indispensable enzyme for the construction of a cDNA library. It synthesizes a complementary DNA (cDNA) strand using a messenger RNA (mRNA) template. This step is crucial because it converts unstable, single-stranded RNA into stable, double-stranded DNA that can be cloned into vectors. This allows researchers to study only the genes that were actively being expressed in a tissue.

87. (C) Lack of introns allowing bacterial translation
A primary advantage of cDNA libraries is that they lack introns, which are non-coding sequences found in eukaryotic genes. Bacteria do not possess the machinery required to splice introns out of primary transcripts. Therefore, using cDNA allows for the direct translation of eukaryotic genes into functional proteins within a bacterial host, making it a critical tool for recombinant protein production and analysis.

88. (D) 3' poly(A) tail of mRNA
Oligo(dT) primers are used during cDNA synthesis to specifically target and bind to the 3' polyadenylated (poly(A)) tail of eukaryotic messenger RNA. Because most mature mRNAs possess this tail, the primer provides a starting point for reverse transcriptase to begin copying the RNA into DNA. This selective binding ensures that primarily protein-coding transcripts are represented in the resulting cDNA library.

89. (A) Screening DNA libraries for a specific gene
Colony hybridization is a powerful technique used to screen genomic or cDNA libraries to identify a specific gene of interest. It involves transferring bacterial colonies from a culture plate to a membrane and then lysing them to release their DNA. A labeled probe is then used to detect the target sequence through hybridization, allowing researchers to pinpoint the exact colony containing the desired clone.

90. (A) Probe
In the context of library screening, a probe is a specific DNA or RNA fragment that has been labeled with a radioactive isotope or a fluorescent tag. The probe is designed to be complementary to the target gene sequence. By allowing the probe to hybridize with the library's DNA, researchers can visually detect and isolate the clones that contain the matching genetic material.

91. (C) $N = \dfrac{\ln(1-P)}{\ln(1-f)}$

The formula $N = \dfrac{\ln(1-P)}{\ln(1-f)}$ is used to calculate
The number of clones (N) required to ensure that a specific genomic sequence is represented in a library with a given probability (P). Here, 'f' represents the fraction of the genome contained in a single average insert. This statistical approach helps researchers determine the necessary library size to achieve comprehensive genomic coverage.

92. (D) Synthesis of complementary DNA from an RNA template
The synthesis of complementary DNA from an RNA template is a step exclusively used in the construction of cDNA libraries, not genomic libraries. Genomic libraries are created by directly fragmenting and cloning the organism's total chromosomal DNA. Therefore, identifying RNA-dependent DNA synthesis as a part of genomic library construction is incorrect, as it bypasses the direct use of the organism's stable genomic DNA.

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It regulates the transition of cells through the various phases of the cell cycle. While auxins like Indole-3-acetic acid are primarily associated with root initiation and apical dominance, zeatin specifically stimulates cytokinesis and lateral bud development in cultured explants.

20. (A) P-2, Q-1, R-4, S-3
EDTA is used for iron chelation to ensure nutrient availability, while sucrose serves as both an osmoticum and a carbon source. Myo-inositol functions as a vitamin-like growth enhancer critical for cell wall biosynthesis. Kinetin is a cytokinin that promotes cell division and shoot morphogenesis. These components work together to provide a balanced chemical environment for the successful growth of cultures.

21. (C) Magnesium
Magnesium is a vital macronutrient that serves as the central atom in the chlorophyll molecule, making it indispensable for photosynthesis. Additionally, it acts as an essential cofactor and activator for many enzymes involved in carbohydrate metabolism and nucleic acid synthesis. Without adequate magnesium, plants exhibit chlorosis and stunted growth due to impaired energy production and disrupted enzymatic activities during development.

22. (B) Agar fails to solidify properly
The pH of tissue culture media is critical for proper consistency and nutrient availability. If the pH drops below 4.5, the agar fails to solidify properly after sterilization, resulting in a liquid or semi-solid medium. This failure occurs because the acidic environment catalyzes the hydrolysis of the agar polysaccharides, preventing the formation of the required gel matrix for supporting explants.

23. (D) Gibberellic acid
Gibberellic acid is a plant growth regulator predominantly used in embryo culture to overcome physiological dormancy. It stimulates the production of enzymes that mobilize stored food reserves, facilitating the germination and growth of the embryo. By bypassing the need for natural chilling or after-ripening periods, gibberellic acid ensures the rapid development of plants from embryos that might otherwise remain dormant.

24. (A) Adsorb toxic phenolic exudates
Activated charcoal is added to tissue culture media primarily to adsorb toxic metabolic byproducts, particularly phenolic exudates produced by wounded explants. These phenolics can oxidize and darken the medium, leading to tissue necrosis and inhibited growth. By removing these inhibitory substances and providing a dark environment, activated charcoal helps improve the survival and regeneration rates of sensitive plant species in vitro.

25. (A) I, II, III and V
Embryo rescue, anther culture, and ovule culture are essential techniques for overcoming reproductive barriers and producing haploids. Somaclonal variation introduces new genetic diversity during the callus phase. However, endosperm culture typically generates triploid plants rather than diploids because the endosperm tissue is naturally triploid. Thus, statements regarding embryo rescue, anther culture, somaclonal variation, and ovule culture are correct for their applications.

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26. (A) Post-zygotic incompatibility
Embryo rescue is an essential technique used to overcome post-zygotic incompatibility in interspecific or intergeneric crosses. In such hybrids, fertilization occurs successfully, but the resulting embryo often aborts due to endosperm failure or genetic imbalances. By excising the immature embryo and culturing it on a specialized nutrient medium, researchers can "rescue" the hybrid and allow it to develop into a mature plant.

27. (D) Colchicine
Colchicine is a powerful chemical agent used to induce chromosome doubling in haploid plants produced through tissue culture. It functions by inhibiting spindle fiber formation during mitosis, preventing the separation of sister chromatids and resulting in a diploid cell. This process is crucial for creating homozygous fertile lines, as it converts sterile haploids into fertile double haploids with restored chromosome pairs.

28. (A) Endosperm
Endosperm tissue is the primary target for producing triploid plants because it naturally possesses a triploid ($3n$) genetic constitution. Unlike other somatic tissues which are diploid, the endosperm is formed by the fusion of a male

Cauliflower Mosaic Virus. In its natural context, it ensures the robust transcription of the viral genome within the host plant. Due to its ability to drive very high levels of gene expression across a wide range of plant species, it has become one of the most widely used promoters.

103. (C) Restrict protein expression to vulnerable tissues
Researchers often choose tissue-specific promoters for pest-resistance genes to restrict protein expression to the tissues most vulnerable to attack. This approach reduces the overall metabolic burden on the host plant, as energy is not wasted producing the toxin in tissues that are not targeted by the pest. Additionally, it helps minimize potential environmental impacts on non-target organisms that do not consume those tissues.

104. (A) Monocots
The maize ubiquitin promoter (Ubi-1) is a highly efficient constitutive promoter frequently utilized for driving transgene expression in monocotyledonous plants like rice, wheat, and maize. In monocots, Ubi-1 often performs significantly better than the CaMV 35S promoter, providing more stable and higher levels of protein production. Its widespread use stems from its ability to ensure consistent expression across various tissues and stages.

105. (A) Inducible
A heat-shock promoter is a type of inducible promoter that is activated only when the plant is exposed to high temperatures. This natural regulatory mechanism allows the plant to produce protective proteins precisely when heat stress occurs. In biotechnology, these promoters are used to switch on transgenic traits at specific times, providing controlled expression that avoids the continuous metabolic costs of constitutive production.

106. (A) Phaseolin - Constitutive
The phaseolin promoter is a well-known tissue-specific promoter, not a constitutive one. It is derived from common bean plants and naturally drives gene expression exclusively during seed development. Incorrectly classifying it as constitutive ignores its specialized role in restricting transgene expression to a specific developmental stage and tissue. In contrast, promoters like CaMV 35S are examples of truly constitutive regulatory elements in biotechnology.

107. (C) Cis-acting elements
Synthetic promoters are engineered by combining a core promoter sequence with various cis-acting elements or enhancers to achieve precise control over gene expression. By rearranging these regulatory motifs, researchers can create custom promoters with improved strength, higher tissue specificity, or novel responses to environmental triggers. This advanced engineering provides a powerful tool for optimizing the performance of transgenes in complex agricultural systems.

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108. (B) II, III and IV
Promoters function by binding RNA polymerase to initiate transcription. Introns can significantly enhance the efficiency of promoters in monocots, a phenomenon known as intron-mediated enhancement. The NOS promoter is indeed derived from Agrobacterium. However, monocot promoters are generally less efficient in dicots. Therefore, statements regarding introns, the NOS promoter, and the basic function of promoters correctly describe their roles in plant biotechnology.

109. (A) Crown gall disease
Agrobacterium tumefaciens is a soil-borne bacterium that naturally causes crown gall disease in a wide range of dicotyledonous plants. The disease is characterized by the formation of large, disorganized tumor-like growths, or galls, typically at the root-stem junction. This occurs because the bacterium transfers its own genetic material into the plant cells, forcing them to overproduce growth hormones and specialized nutrients.

110. (C) T-DNA
The T-DNA (Transferred DNA) is the specific segment of the Ti (Tumor-inducing) plasmid that is cut, transferred, and integrated into the host plant's nuclear genome during Agrobacterium infection. While other regions of the plasmid, like the vir genes, are essential for the transfer process itself, they remain within the bacterium. The T-DNA contains the genes responsible for gall formation.

111. (A) Left and Right borders
The T-DNA region is physically defined by two nearly identical 25-base pair direct repeat

slicer activity within the RISC complex. siRNAs are small RNAs characterized by perfect complementarity to their target mRNA. miRNAs serve as endogenous regulators that play critical roles in plant development. Together, these components form the essential machinery of the RNA interference pathway in plants.

167. (D) 24-nt siRNAs
RNA-directed DNA methylation (RdDM) is a sophisticated epigenetic mechanism in plants that is guided by 24-nucleotide small interfering RNAs (siRNAs). These specific small RNAs direct the methylation of complementary DNA sequences, typically at promoter regions, leading to transcriptional gene silencing. RdDM plays a vital role in maintaining genome stability by silencing transposable elements and regulating the expression of various endogenous plant genes.

168. (A) It can move systemically through the phloem to distant tissues.
A unique feature of RNA interference in plants is its ability to move systemically through the phloem to distant tissues. This allows the silencing signal to spread from the site of initiation throughout the entire plant, providing a coordinated defense against viral infections. This systemic transmission ensures that newly developing leaves and organs are also protected, a characteristic that is generally essential.

169. (C) Create specific, targeted alterations in a known DNA sequence
Site-directed mutagenesis is a powerful molecular biology technique used to introduce specific, targeted alterations into a known DNA sequence. This allows researchers to change individual amino acids in a protein or modify regulatory elements in a promoter with high precision. By studying the effects of these exact mutations, scientists can gain deep insights into the function and structure of genes and proteins.

170. (A) A sequence with a desired mismatch
Oligonucleotide-directed mutagenesis utilizes a synthetic primer that is designed to be mostly complementary to the target DNA but contains a specific desired mismatch. This mismatch represents the intended mutation, such as a base substitution, insertion, or deletion. When the primer is used in a DNA synthesis reaction, the mutation is incorporated into the newly formed strand, creating a mutated version.

171. (D) It cleaves the parental, methylated DNA template.
In PCR-based site-directed mutagenesis, the DpnI enzyme is used to selectively cleave the parental, methylated DNA template. Because the template DNA is isolated from E. coli, it carries methyl groups, whereas the newly synthesized mutated DNA produced during the PCR reaction is unmethylated. This enzymatic step ensures that only the desired mutated plasmids are used for subsequent transformation into host cells.

172. (D) It possesses 3' to 5' proofreading activity, preventing unintended secondary mutations.
High-fidelity DNA polymerases are critical for site-directed mutagenesis because they possess 3' to 5' proofreading exonuclease activity. This function allows the enzyme to correct errors made during DNA synthesis, significantly reducing the frequency of unintended secondary mutations. Using such a polymerase ensures that only the specifically designed mutation is introduced into the plasmid, maintaining the overall genetic integrity of the final construct.

173. (A) It can only be used to create single base substitutions, not deletions or insertions.
Oligonucleotide-directed mutagenesis is a versatile technique that is not limited to single base substitutions. It can also be used to create precise deletions or insertions by carefully designing the synthetic primer. While it does require a DNA template and a transformation step to recover the mutant plasmid, its ability to generate various types of targeted mutations makes it an essential tool.

174. (C) Four
Overlap extension PCR is a mutagenesis strategy that uniquely requires four specific primers to generate a mutated DNA fragment. Two "outer" primers flank the entire region of interest, while two "inner" primers carry the desired mutation and have overlapping sequences. This technique involves two separate PCR rounds that eventually merge the fragments, allowing for the precise introduction of mutations.

175. (A) Removing a fragment of DNA with restriction enzymes and replacing it with a synthetic, mutated double-stranded DNA sequence
Cassette mutagenesis is a technique that involves removing a specific segment of DNA from a

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and integrated. By replacing these oncogenes with desirable transgenes and selectable markers, researchers can use Agrobacterium as a safe and effective vehicle for genetic engineering.

121. (C) Gold or Tungsten
Biolistics, or the gene gun method, relies on coating DNA onto microscopic metal carriers, typically made of gold or tungsten. These metals are chosen because they are chemically inert, dense enough to penetrate plant cells at high velocities, and non-toxic to the tissue. The DNA-coated microcarriers are then accelerated using high-pressure helium gas to deliver the genetic material directly into the target cells.

122. (B) Short electrical pulses to create transient membrane pores
Electroporation is a direct gene transfer technique that uses short, high-voltage electrical pulses to create transient, microscopic pores in the cell membrane. These pores allow DNA molecules from the surrounding medium to enter the cytoplasm. Once the pulse ends, the membrane reseals, trapping the DNA inside. While highly effective for protoplasts, the presence of a rigid cell wall can limit its efficiency.

123. (D) Single cells or protoplasts
Microinjection is a precise technique primarily used for transforming individual cells or protoplasts. It involves using an extremely fine glass needle, controlled by a micromanipulator, to physically inject a DNA solution directly into the nucleus or cytoplasm. While technically demanding and low-throughput, microinjection ensures that the DNA is delivered exactly where it is needed, making it useful for specialized research.

124. (D) Effective for recalcitrant monocots
A major advantage of biolistics over Agrobacterium-mediated transformation is its effectiveness for transforming recalcitrant monocot species, such as maize and wheat. Many monocots were historically difficult to infect with Agrobacterium, but the physical delivery of DNA via the gene gun bypasses biological compatibility barriers. This has made biolistics a fundamental tool for the genetic improvement of many important cereal and grain crops.

125. (B) I, II, IV and V
PEG-mediated transfer requires protoplasts, while microinjection uses a micromanipulator. Biolistics is unique in its ability to transform organelles like chloroplasts. Direct transfer methods often lead to complex integration patterns with multiple copies. However, electroporation is generally inefficient on intact, thick-walled cells due to the barrier of the cell wall. Thus, the statements regarding PEG, biolistics, microinjection, and integration patterns are correct.

126. (B) Create micro-wounds in the plant tissue
Sonication-assisted Agrobacterium-mediated transformation (SAAT) uses ultrasound waves to create microscopic wounds throughout the plant tissue. These micro-wounds provide numerous entry points for Agrobacterium and increase the surface area for infection. By facilitating better access to the target cells, sonication significantly enhances the transformation efficiency in species that are otherwise difficult to transform using standard Agrobacterium protocols.

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127. (A) Helium gas pressure
When using a helium-driven gene gun, optimizing the helium gas pressure is critical for successful transformation. The pressure determines the velocity at which the DNA-coated microcarriers are launched. If the pressure is too low, the particles will not penetrate the cell wall; if it is too high, it may cause excessive cellular damage and death. Finding the balance ensures efficient DNA delivery.

128. (B) Higher frequency of multiple copy and rearranged insertions
Compared to Agrobacterium-mediated transformation, direct gene transfer methods like biolistics frequently result in a higher frequency of multiple-copy integrations and complex chromosomal rearrangements. Because the DNA is delivered physically, multiple fragments can integrate at a single locus or at various sites throughout the genome. This can sometimes lead to gene silencing or unpredictable expression levels, necessitating careful screening.

129. (B) Microscopic puncturing of cell walls during vortexing
Silicon carbide whiskers mediate gene transfer through a physical process where the whiskers puncture the cell walls and membranes during

sequences known as the Left and Right Borders. These sequences are the only parts of the T-DNA that are strictly required for its transfer and integration. During infection, the Agrobacterium Vir proteins recognize these borders and initiate the nicking and release of the single-stranded T-DNA molecule for transport.

112. (D) Acetosyringone
Acetosyringone is a phenolic compound naturally released by wounded plant cells that acts as a powerful signal to attract Agrobacterium. It specifically binds to the VirA sensor protein on the bacterial membrane, triggering the activation of the entire vir operon. This chemical signaling is a critical first step in the transformation process, ensuring that the bacterium initiates DNA transfer only when nearby.

113. (A) VirD2
Within the Agrobacterium vir operon, the VirD2 protein functions as a specialized endonuclease that recognizes and nicks the T-DNA at the border sequences. After nicking, VirD2 remains covalently attached to the 5' end of the single-stranded T-DNA. In this role, it not only guides the DNA into the plant cell but also protects it from degradation and facilitates its integration.

114. (A) It coats the single-stranded T-DNA, protecting it from nucleases.
The VirE2 protein plays a crucial role in T-DNA transfer by coating the single-stranded T-DNA molecule as it enters the plant cell. This coating protects the DNA from being degraded by host nucleases and helps maintain it in an elongated, thin configuration that can easily pass through nuclear pores. By ensuring the integrity of the T-DNA, VirE2 significantly increases the transformation efficiency.

115. (B) I, III and IV
Binary vector systems utilize two separate plasmids: a small shuttle vector containing the T-DNA and a larger helper plasmid containing the vir genes. The vir genes provide the machinery for transfer but are not themselves transferred. This system is highly advantageous because the small shuttle vector can be easily manipulated in E. coli before being introduced into Agrobacterium for plant transformation experiments.

116. (D) Auxin and Cytokinin
Natural T-DNA carries genes that encode enzymes for the biosynthesis of the primary plant hormones auxin and cytokinin. Once integrated into the plant genome, these genes are expressed, leading to the overproduction of these hormones. This hormonal imbalance causes the rapid, uncontrolled cell division characteristic of crown gall tumors, providing a protected environment and a steady supply of nutrients for the bacterium.

117. (A) Nutrient source for Agrobacterium
Opines are unique chemical compounds synthesized by transformed plant cells using genes located on the integrated T-DNA. These molecules are specifically secreted by the tumors to serve as an exclusive nutrient and carbon source for the infecting Agrobacterium. Other soil microbes cannot metabolize opines, giving Agrobacterium a distinct competitive advantage and a dedicated "ecological niche" within the host plant's environment.

118. (A) I and II
The VirA and VirG proteins constitute a classic two-component regulatory system that allows Agrobacterium to sense and respond to the plant environment. VirA acts as a membrane-bound sensor kinase that detects phenolic signals like acetosyringone. Upon activation, it phosphorylates VirG, a transcriptional regulator that then switches on the expression of all other vir genes, initiating the DNA transfer and infection process.

119. (D) Arabidopsis thaliana
Arabidopsis thaliana is the primary model organism used for Agrobacterium-mediated transformation via the floral dip method. This technique involves dipping the developing flowers of the plant into a suspension of Agrobacterium, which then infects the female gametophytic tissue. Because it bypasses the need for tissue culture and regeneration, floral dip is a highly efficient and widely used method for generating transgenic Arabidopsis.

120. (D) Oncogenes for auxin/cytokinin synthesis
Disarming a Ti plasmid involves the removal of the oncogenes responsible for auxin and cytokinin synthesis from the T-DNA region. This prevents the formation of crown gall tumors while still allowing the T-DNA to be transferred

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transgenic plants without the need for destructive sampling or toxic dyes.

139. (C) They are strictly required for the survival of transformed cells.
Reporter genes are invaluable tools for studying promoter activity and confirming transgene expression, but they are not strictly required for the survival of transformed cells. Unlike selectable markers, which provide a survival advantage under specific conditions, reporters are used solely for detection and quantification. Therefore, the statement that they are essential for cell survival is incorrect, as cells can thrive without them.

140. (A) P-3, Q-1, R-2, S-4
The hpt gene confers resistance to hygromycin, while GFP provides fluorescence under UV light for visualization. The GUS reporter requires the X-Gluc substrate to produce a blue color. The PMI gene is used for positive selection by allowing cells to utilize mannose as a carbon source. These markers and reporters are essential for identifying and characterizing successful plant transformation events.

141. (C) Utilization of a unique metabolic growth substrate
Positive selection markers, such as the phosphomannose isomerase (PMI) gene, function by allowing transformed cells to utilize a unique metabolic growth substrate that untransformed cells cannot use. For example, when mannose is the sole carbon source, only cells expressing PMI can convert it into a usable form for growth. This approach avoids the use of antibiotics or herbicides in the selection.

142. (D) Beta-glucuronidase
The uidA gene, commonly referred to as the GUS gene, encodes the specific enzyme beta-glucuronidase. This enzyme is highly valued in plant biotechnology because there is very little endogenous GUS activity in most plant species, which minimizes background signals. When the enzyme reacts with suitable substrates like X-Gluc, it produces a clear visual or fluorometric output, facilitating the study of gene expression.

143. (D) CAT
The chloramphenicol acetyltransferase (CAT) gene was one of the first reporter genes used in plant transformation studies. It encodes an enzyme that inactivates the antibiotic chloramphenicol by transferring an acetyl group from acetyl-CoA. By measuring the rate of this acetylation reaction in tissue extracts, researchers could quantify the level of transgene expression, providing an early method for evaluating promoter strength.

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144. (B) Glyphosate
A specific mutation in the EPSPS gene is utilized as a selectable marker to confer resistance to the herbicide glyphosate. Glyphosate normally inhibits the wild-type EPSPS enzyme, which is essential for the biosynthesis of aromatic amino acids. The mutated version of the enzyme is insensitive to the herbicide, allowing transformed plant cells to survive and grow even in its presence during selection.

145. (B) DNA
Southern blotting is a fundamental molecular technique used to verify the presence and integration of specific DNA sequences within a sample. By separating DNA fragments by size via electrophoresis and transferring them to a membrane, researchers can use a labeled probe to detect the target gene. This method is critical for confirming that a transgene has been successfully integrated into the host.

146. (A) Messenger RNA
Northern blotting is a specialized laboratory technique designed to analyze the expression levels of specific messenger RNA (mRNA) sequences. Similar to Southern blotting, RNA is separated by size and transferred to a membrane for detection with a complementary probe. This allows researchers to determine if a transgene is being actively transcribed and to compare its expression across different tissues or conditions.

147. (C) Specific antibodies
In Western blotting, specific antibodies are used as probes to detect and quantify target proteins within a sample. After proteins are separated by electrophoresis and transferred to a membrane, a primary antibody binds to the protein of interest. This is followed by a secondary antibody that produces a detectable signal. This technique confirms that a transgene is successfully translated into its protein.

vigorous vortexing. When an explant or protoplasts are mixed with the whiskers and DNA, the sharp, needle-like structures create transient openings that allow the genetic material to enter the cells. This method is simple and inexpensive, although its efficiency can vary.

130. (C) A is true but R is false.
Chloroplast transformation is primarily achieved via biolistics because the gene gun can physically deliver DNA through the multiple membranes of the plastid. In contrast, Agrobacterium naturally targets the plant nucleus and lacks a mechanism to specifically transfer T-DNA into the chloroplast genome. Therefore, while biolistics is a successful tool for plastid engineering, the reasoning involving natural Agrobacterium behavior is scientifically incorrect.

131. (C) Cell wall
The primary challenge when using electroporation on intact plant cells is the presence of the rigid cell wall. This structure acts as a significant physical and electrical barrier that prevents DNA from reaching the plasma membrane. Consequently, electroporation is much more efficient when performed on protoplasts, where the cell wall has been enzymatically removed, allowing the electrical pulses to create pores directly.

132. (D) Artificial lipid vesicle
Liposome-mediated transformation involves encapsulating DNA within artificial lipid vesicles called liposomes. These vesicles can fuse with the plant cell membrane or be taken up by endocytosis, releasing the genetic material into the cytoplasm. This method protects the DNA from degradation by extracellular nucleases and can be used for both protoplasts and some intact tissues, offering a chemical alternative to physical delivery.

133. (A) Differentiate between transformed cells
Selectable markers are essential in plant transformation for differentiating and isolating the few successfully transformed cells from the vast majority of untransformed ones. These genes typically confer resistance to antibiotics or herbicides. When the treated tissue is grown on a selective medium, only the cells containing the transgene survive and proliferate, eventually allowing for the regeneration of fully transgenic plants.

134. (B) Aminoglycosides (e.g., Kanamycin)
The nptII gene, which encodes neomycin phosphotransferase II, confers resistance to aminoglycoside antibiotics such as kanamycin, neomycin, and G418. It functions by phosphorylating these antibiotics, thereby inactivating them and preventing them from inhibiting protein synthesis in the plant cells. Due to its reliability and the relative safety of these antibiotics, nptII is one of the most widely used selectable markers.

135. (D) GUS (uidA)
The GUS (uidA) gene is a popular reporter system that produces a distinct blue coloration in the presence of the substrate X-Gluc. The gene encodes the enzyme beta-glucuronidase, which hydrolyzes the substrate to form an insoluble blue indigo dye. This visual signal allows researchers to easily identify transformed tissues and study the spatial and temporal patterns of gene expression in transgenic plants.

136. (A) Non-destructive in vivo visualization
A primary advantage of the Green Fluorescent Protein (GFP) over the GUS reporter is that it allows for non-destructive, in vivo visualization of gene expression. GFP fluoresces naturally under UV or blue light without the need for additional chemical substrates or dyes. This enables researchers to observe the same living plant tissue over time, monitoring developmental processes and protein localization.

137. (C) Phosphinothricin (Glufosinate)
The bar gene serves as a selectable marker by conferring resistance to the herbicidal compound phosphinothricin, also known as glufosinate. It encodes the enzyme phosphinothricin acetyltransferase, which chemically modifies the herbicide by acetylation, rendering it non-toxic. This allows transformed plant cells to grow and regenerate on media containing the herbicide, effectively screening for successful gene integration during the transformation process.

138. (A) Luciferin
In the bioluminescent reporter system derived from the firefly, the substrate luciferin is oxidized by the enzyme luciferase in the presence of ATP and oxygen. This chemical reaction results in the emission of visible light. By measuring the intensity of this bioluminescence, researchers can accurately quantify gene expression levels in

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cleavage of the mRNA before it can be translated into a protein, the specific gene is effectively "silenced." This mechanism is a powerful tool in biotechnology for down-regulating specific genes to study their function or improve traits.

158. (B) dsRNA formation, Dicer cleavage, RISC assembly, mRNA degradation
The RNAi pathway begins with the formation of double-stranded RNA (dsRNA), which is then recognized and cleaved by the Dicer enzyme into small interfering RNAs (siRNAs). These siRNAs are subsequently incorporated into the RNA-Induced Silencing Complex (RISC). Finally, the RISC uses the siRNA as a guide to identify and degrade the complementary target mRNA, resulting in successful gene silencing within the cell.

159. (A) Dicer
Dicer is a specialized RNase III-like enzyme responsible for cleaving long double-stranded RNA (dsRNA) molecules into short interfering RNAs (siRNAs), typically 21 to 24 nucleotides in length. It acts as the "molecular scissors" that initiate the RNA interference process. By producing these small guide RNAs, Dicer enables the cell's silencing machinery to target and degrade specific messenger RNA sequences with high precision.

160. (D) Single-stranded RNA forming hairpin loop structures
MicroRNAs (miRNAs) are a class of small RNAs that are typically derived from endogenous primary transcripts that form characteristic single-stranded hairpin loop structures. These precursors are processed by Dicer-like enzymes into mature miRNAs. In plants, miRNAs play a fundamental role in regulating gene expression during development and in response to environmental stress by targeting specific mRNAs for cleavage or translational inhibition.

161. (B) Argonaute
Within the RNA-Induced Silencing Complex (RISC), the Argonaute protein serves as the catalytic "slicer" responsible for the final cleavage of the target mRNA. Guided by the incorporated small RNA molecule, Argonaute identifies the complementary sequence on the mRNA and performs the precise endonucleolytic cut. This action prevents the mRNA from being translated into a protein, effectively achieving gene silencing.

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162. (A) siRNAs typically have perfect complementarity to their target, leading to mRNA cleavage.
In plants, siRNAs primarily differ from miRNAs in their level of target specificity; siRNAs typically exhibit perfect or near-perfect complementarity to their target mRNA. This high degree of matching leads directly to the precise cleavage and degradation of the mRNA by the RISC complex. In contrast, miRNAs may have more mismatches, which can sometimes lead to the inhibition of translation.

163. (C) RNA interference
The phenomenon of co-suppression, first observed in transgenic petunias, was an early and unexpected manifestation of RNA interference. Researchers attempting to deepen the purple color by overexpressing a pigment gene instead produced white or variegated flowers. This occurred because both the transgene and the endogenous gene were silenced by the plant's RNAi machinery, providing a landmark discovery in gene regulation.

164. (D) Hairpin RNA (hpRNA)
To engineer virus resistance via RNAi, plants are typically transformed with genetic constructs designed to transcribe hairpin RNA (hpRNA). These constructs contain a sequence from the target virus in both sense and antisense orientations, separated by a spacer. When transcribed, the RNA folds back on itself to form a double-stranded structure that triggers the plant's silencing machinery against the virus.

165. (C) To overcome the plant's RNAi defense mechanism
Viral Suppressors of RNA Silencing (VSRs) are specialized proteins produced by many plant viruses to overcome the host's RNAi-based defense mechanism. These proteins function by binding to small RNAs or interfering with key components of the silencing machinery, such as Dicer or Argonaute. By inhibiting the plant's ability to degrade viral RNA, VSRs allow the virus to replicate and spread.

166. (A) P-3, Q-1, R-4, S-2
Dicer is an RNase III-like enzyme that processes dsRNA, while Argonaute provides the catalytic

and bind to almost any desired target DNA sequence.

185. (C) FokI
Zinc Finger Nucleases (ZFNs) achieve targeted DNA cleavage by utilizing the non-specific nuclease domain from the FokI restriction enzyme. The FokI domain must dimerize to become active, which is achieved by designing two separate ZFNs that bind to adjacent sites on the DNA. This requirement for dimerization increases the specificity of the system, ensuring that cleavage only occurs at the target.

186. (A) Non-Homologous End Joining (NHEJ)
Double-strand breaks (DSBs) induced by genome editing tools are predominantly repaired by the Non-Homologous End Joining (NHEJ) pathway. This cellular repair mechanism is inherently error-prone, often introducing small insertions or deletions (indels) at the site of the break. These mutations frequently cause frame-shifts that disrupt the gene's coding sequence, making NHEJ the primary method used for creating efficient gene knockouts.

187. (C) Precise gene insertion or replacements
Homology-Directed Repair (HDR) is a precise cellular repair mechanism utilized in genome editing to achieve targeted gene insertions or specific base replacements. Unlike the error-prone NHEJ pathway, HDR requires a provided DNA template with sequences homologous to the site of the double-strand break. By using this template, the cell can accurately repair the DNA, allowing for the introduction of modifications.

188. (D) It relies on RNA-DNA base pairing for target recognition.
A key characteristic that distinguishes CRISPR-Cas9 from ZFNs and TALENs is its reliance on simple RNA-DNA base pairing for target recognition. While ZFNs and TALENs require the complex engineering of protein domains for every new target, CRISPR-Cas9 uses a customizable guide RNA. This makes the CRISPR system much easier, faster, and more versatile to use for diverse genome editing applications.

189. (A) Gene interference or activation
A dead Cas9 (dCas9) is a modified version of the enzyme that has lost its endonuclease activity but still retains the ability to bind to DNA. When fused with transcriptional activators or repressors, dCas9 can be used for gene interference or activation. This allows researchers to precisely regulate the expression of specific genes without making any permanent changes to the genomic sequence.

190. (A) Both A and R are true and R is the correct explanation of A.
CRISPR-Cas9 is uniquely powerful because it allows for multiplex gene editing, where several different genes can be modified simultaneously. This is achieved by delivering multiple guide RNAs along with a single Cas9 nuclease into the cell. Each guide RNA directs the Cas9 to a different genomic target. This capability significantly accelerates research and allows for the study of complex multigene.

191. (A) Cytidine or adenine deaminases
Base editing technologies utilize a modified Cas9, such as a nickase, fused to cytidine or adenine deaminase enzymes. These systems allow for the direct conversion of one DNA base into another (e.g., C to T or A to G) without inducing a double-strand break. By avoiding the unpredictable outcomes of the NHEJ pathway, base editors provide a highly precise method for engineering.

192. (D) Cleavage of DNA sequences similar to the target
Off-target effects in CRISPR-Cas9 refer to the unintended cleavage of DNA sequences that are similar, but not identical, to the intended target site. This occurs when the guide RNA binds to non-target regions with several mismatches. Minimizing these effects is a major focus in genome editing research, as unintended mutations could potentially disrupt other essential genes or lead to unpredictable consequences.

193. (B) Sporulation
Bacillus thuringiensis is a soil bacterium that produces insecticidal crystal proteins, known as Cry proteins, specifically during the sporulation phase of its life cycle. These proteins aggregate into parasporal crystals that are released along with the spores. The production of these toxins is an evolutionary strategy that provides the bacterium with a source of nutrients as it infects and kills susceptible insects.

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plasmid using restriction enzymes and replacing it with a synthetic, mutated double-stranded DNA sequence known as a "cassette." This method is highly efficient for introducing multiple mutations or completely redesigning a specific region of a gene. It relies on the availability of unique restriction sites flanking.

176. (D) Mutation should be located near the primer center
When designing primers for site-directed mutagenesis, it is essential that the intended mutation is located near the center of the oligonucleotide. This ensures that there is sufficient complementary sequence on both sides of the mismatch to allow the primer to bind stably and specifically to the template DNA. Proper positioning of the mutation is critical for achieving high efficiency and accuracy.

177. (B) dUTPase (dut-)
The uracil-DNA glycosylase (UDG) based method of mutagenesis (Kunkel method) utilizes an E. coli strain deficient in the enzyme dUTPase (dut-). This deficiency results in the incorporation of uracil into the DNA template. When the mutated strand is synthesized in vitro and transformed back into a wild-type E. coli strain, the uracil-containing parental strand is selectively degraded, increasing the efficiency.

178. (A) Complete digestion of the parental template by DpnI
The efficiency of the QuikChange mutagenesis protocol is primarily determined by the complete digestion of the parental DNA template by the DpnI enzyme. DpnI specifically targets methylated DNA, which is characteristic of the original template. If digestion is incomplete, untransformed parental plasmids will persist, leading to a high background of non-mutated colonies and reducing the overall success rate.

179. (C) Protein engineering to alter enzyme activity or stability
Site-directed mutagenesis is most frequently applied in biotechnology for protein engineering, where it is used to alter the amino acid sequence of enzymes to improve their activity, stability, or specificity. By making precise changes to the protein's structure, researchers can create optimized versions for industrial, medical, or agricultural applications. This technique is fundamental for understanding the relationship between protein structure.

180. (D) They span the sequence to be deleted, omitting it from the amplicon.
A deletion mutation can be achieved using PCR-based mutagenesis by designing primers that span the entire sequence to be removed, effectively omitting it from the resulting amplicon. When these primers bind to the template, they leave out the target region during synthesis. After the PCR and subsequent ligation or circularization, the resulting plasmid will completely lack the specific deleted DNA segment.

181. (C) The single guide RNA (sgRNA)
In the CRISPR-Cas9 system, the specificity of the genomic target is dictated by the sequence of the single guide RNA (sgRNA). The sgRNA contains a 20-nucleotide spacer that is designed to be complementary to the target DNA site. By simple base-pairing, the sgRNA guides the Cas9 enzyme to the precise location in the genome where the DNA cleavage occurs.

182. (B) RNA-guided DNA endonuclease
Cas9 is best described as an RNA-guided DNA endonuclease that serves as the molecular scissors in the CRISPR system. It forms a complex with the guide RNA, which directs it to a specific DNA sequence through complementary base pairing. Once the target is identified and verified by the presence of a PAM sequence, Cas9 induces a precise double-strand break.

183. (D) Protospacer Adjacent Motif (PAM)
The Protospacer Adjacent Motif (PAM) is a short, specific DNA sequence, such as 5'-NGG-3' for Cas9, that must be located immediately downstream of the target site. It is absolutely required for the Cas9 enzyme to recognize and bind to the DNA. The PAM acts as a critical safety check, ensuring that the CRISPR system only cleaves foreign or targeted DNA.

184. (A) One
TALENs (Transcription Activator-Like Effector Nucleases) recognize specific DNA sequences through modular repeats of amino acids. Within each repeat, two specific amino acids, known as the Repeat Variable Di-residue (RVD), determine the specificity for a single base pair. By assembling these repeats in a specific order, researchers can engineer TALENs to recognize

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148. (D) Quantification of DNA during amplification
Real-time PCR (qPCR) differs from conventional PCR primarily by its ability to quantify DNA molecules during the amplification process. By using fluorescent dyes or probes that emit light as DNA is synthesized, the system monitors the reaction in real-time. This provides a highly sensitive and accurate measurement of the initial amount of target nucleic acid, which is essential for analyzing gene expression.

149. (C) Capillary action or electro-transfer
In a Southern blot, the transfer of DNA from the agarose gel to a nitrocellulose or nylon membrane is facilitated by capillary action or electro-transfer. Capillary action uses a flow of buffer to pull the DNA out of the gel and onto the membrane. Alternatively, electro-transfer uses an electric field to move the DNA. Both methods ensure that the DNA fragments are efficiently transferred.

150. (C) A is true but R is false.
Western blotting is a critical technique used to confirm the presence and accumulation of a transgenic protein within a host plant. It relies on antibody-mediated detection to identify specific proteins. However, the reasoning provided is incorrect because Western blotting does not detect DNA integration; rather, it analyzes the final product of gene expression, which is the protein, after transcription and translation.

151. (D) SYBR Green I
SYBR Green I is the most commonly used non-specific intercalating dye in real-time PCR assays. It fluoresces strongly only when bound to double-stranded DNA. As the PCR reaction progresses and more DNA is synthesized, the fluorescence intensity increases proportionally. While it is inexpensive and easy to use, it binds to all double-stranded DNA, including non-specific products and primer dimers.

152. (A) Southern blot
To determine the exact copy number of a transgene integrated into the plant genome, Southern blotting remains the most conclusive and reliable technique. By digesting the genomic DNA with specific restriction enzymes and analyzing the resulting banding pattern with a labeled probe, researchers can distinguish between single-copy and multi-copy integration events. This information is vital for selecting stable and predictable transgenic lines.

153. (D) Sodium hydroxide (NaOH)
During the Southern blotting procedure, DNA is typically denatured into single strands using a strong alkaline solution, such as sodium hydroxide (NaOH). Denaturation is essential because it allows the subsequently applied labeled DNA probe to hybridize with its complementary target sequence on the membrane. This chemical step ensures that the double-stranded fragments are separated while remaining fixed in their respective positions.

154. (A) Transgene mRNA expression levels
Reverse Transcriptase PCR (RT-PCR) is an essential prerequisite for assessing the mRNA expression levels of a transgene. This technique involves first converting the messenger RNA into complementary DNA (cDNA) using the enzyme reverse transcriptase, followed by standard PCR amplification. By analyzing the resulting cDNA, researchers can confirm that the integrated gene is being actively transcribed by the plant's molecular machinery.

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155. (D) Probes complementary to the target sequence
TaqMan chemistry ensures high target specificity in real-time PCR by utilizing dual-labeled oligonucleotide probes that are perfectly complementary to the target sequence. During the extension phase of PCR, the Taq polymerase's 5' exonuclease activity cleaves the probe, separating a fluorescent reporter from a quencher. This results in a signal that is generated only when the probe binds to the correct target.

156. (D) The initial amount of nucleic acid
The Ct (Cycle threshold) value in real-time PCR represents the number of cycles required for the fluorescent signal to cross a predefined threshold. This value is inversely proportional to the initial amount of target nucleic acid in the sample. A lower Ct value indicates a higher starting concentration of the gene, as it takes fewer cycles to reach a detectable level.

157. (C) Degrading target mRNA
RNA interference (RNAi) is a natural biological process where small RNA molecules inhibit gene expression primarily by degrading target messenger RNA (mRNA). By triggering the

194. (A) Specific cell surface receptors in the midgut epithelium
The specific toxicity of Bt Cry proteins is primarily determined by the presence of unique cell surface receptors on the midgut epithelium of susceptible insects. When the protein is ingested, it binds specifically to these receptors, leading to pore formation and the eventual destruction of the gut lining. Insects that lack these exact receptors are unaffected by the toxin, ensuring safety.

195. (C) Lepidoptera
Cry1Ac is a specific class of Bt protein that is highly toxic to insects belonging to the order Lepidoptera, which includes major pests like moths and butterflies. It is widely used in transgenic crops like Bt cotton to control the cotton bollworm. The toxin's specificity ensures that it effectively targets these destructive caterpillars while having minimal impact on most other organisms.

196. (D) Humans lack the specific midgut receptors and alkaline gut pH required for activation.
Cry proteins are harmless to mammals and humans because they lack the specific midgut receptors and the highly alkaline gut environment required to activate the toxin. In the acidic environment of the human stomach, the protein is rapidly digested and broken down like any other dietary protein. This high level of biological specificity makes Bt toxins an exceptionally safe choice for crops.

197. (C) Proteinase inhibitors
Proteinase inhibitors are enzymes engineered into plants to disrupt insect digestion by blocking the breakdown of dietary proteins in the gut. By inhibiting key digestive enzymes like trypsin or chymotrypsin, these proteins deprive the insect of essential amino acids, leading to stunted growth, reduced fertility, and eventual death. This provides an alternative strategy for conferring resistance to various insect pests.

198. (C) I and II
Bt cotton is widely cultivated to control lepidopteran pests like the cotton bollworm, significantly reducing the need for chemical insecticides. The Cry proteins produced by these crops function by forming pores in the insect's midgut membrane, leading to lethal septicemia. By providing continuous and targeted protection, Bt crops offer a more sustainable and environmentally friendly approach to pest management.

199. (C) Planting a refuge of non-Bt crop plants
To prevent or delay the evolution of resistance to Bt toxins, farmers are legally mandated to plant a "refuge" of non-Bt crop plants alongside their transgenic fields. This strategy ensures that a small population of susceptible insects survives and mates with any rare resistant individuals that emerge. The resulting offspring are likely to be susceptible, thereby maintaining the overall effectiveness.

200. (A) P-3, Q-2, R-1, S-4
Cry1 proteins primarily target Lepidoptera, while Cry3 is effective against Coleoptera, and Cry4 targets Diptera like mosquitoes. Vip3A is a distinct class of broad-spectrum vegetative insecticidal proteins. These toxins provide diverse tools for engineering resistance against various insect orders, allowing for the development of crops that are protected against a wide range of agricultural pests and disease vectors.

201. (C) Matching the plant codon usage bias
Achieving high-level expression of bacterial cry genes in transgenic plants required modifying the gene's sequence to match the host plant's codon usage bias. Bacteria and plants often use different preferred codons for the same amino acids. By "humanizing" the gene, researchers ensured that the plant's translation machinery could efficiently produce the Cry protein, leading to effective levels of resistance.

202. (A) Protein digestion in the gut
The cowpea trypsin inhibitor (CpTI) gene confers resistance to various insects by targeting the physiological process of protein digestion. When an insect consumes the transgenic plant tissue, the CpTI protein binds to and inactivates trypsin enzymes in the gut. This prevents the insect from breaking down proteins into essential amino acids, resulting in severe nutritional deficiency that inhibits growth and survival.

203. (C) Stacking genes to delay insect resistance
Gene pyramiding, or stacking, in Bt crops involves the introduction of multiple different insecticidal genes into a single plant variety. By combining toxins with different modes of action or different target sites in the insect gut, this

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277. (C) Creations of the mind, such as inventions and designs
Intellectual Property Rights (IPR) are legal rights granted to inventors or creators to protect their "creations of the mind," such as inventions, literary works, designs, and symbols. These rights provide the creator with exclusive control over the use and commercialization of their work for a specified period. IPR is essential for incentivizing innovation and ensuring that creators are fairly rewarded.

278. (A) 1, 2, 3, 4
The patent application process follows a specific sequence beginning with the formal filing of the application. This is followed by the publication of the application to the public after a set period. Next, the patent office conducts a rigorous examination to ensure all criteria are met. Finally, if the invention is deemed novel and non-obvious, the grant of patent is issued.

279. (D) Non-obviousness (inventive step)
To be patentable, an invention must satisfy three fundamental criteria: novelty, industrial applicability, and non-obviousness (also known as an inventive step). Non-obviousness means that the invention must not be something that a person with ordinary skill in that specific field could have easily thought of. This requirement ensures that patents are only granted for truly innovative and significant technical advancements.

280. (A) World Trade Organization (WTO)
The TRIPS (Trade-Related Aspects of Intellectual Property Rights) Agreement is a major international treaty that establishes minimum standards for IPR regulation among member nations. It is administered by the World Trade Organization (WTO). TRIPS plays a critical role in global trade by ensuring that intellectual property is protected and enforced consistently across different countries, facilitating international innovation and exchange.

281. (C) Commercialization without fair compensation
Biopiracy refers to the controversial practice where biological resources or traditional knowledge from indigenous communities are commercialized by others without fair compensation or legal authorization. This often involves patenting natural genetic resources or traditional medicinal uses without acknowledging the original stewards of that knowledge. International agreements like the CBD aim to prevent biopiracy by promoting equitable benefit-sharing and sovereign rights.

282. (A) A naturally occurring plant variety or seed
Under the Indian Patent Act of 1970, a naturally occurring plant variety or seed cannot be patented. The law specifically excludes plants and animals in whole or in part, as well as biological processes for their production. This provision is designed to ensure that basic genetic resources remain in the public domain and that traditional farming practices and food security are protected.

283. (B) Turmeric (Curcuma longa)
The controversial patent granted on the wound-healing properties of turmeric (Curcuma longa) was successfully revoked after a legal challenge by India. The challenge established "prior art" by providing ancient texts and traditional knowledge showing that these properties had been known and used in India for centuries. This landmark case highlighted the importance of protecting traditional knowledge against illegitimate IPR claims.

284. (B) 20 years
A 'Utility Patent' is typically granted for a fixed period of 20 years from the date of filing the application. During this time, the patent holder has the exclusive right to prevent others from making, using, or selling the invention. In exchange for this temporary monopoly, the inventor must publicly disclose the details of the invention, allowing for eventual public use.

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285. (C) All information made available to the public before a given effective date
In the context of patents, 'Prior Art' refers to all information, knowledge, and evidence that was made available to the public anywhere in the world before the filing date of the patent application. This includes previous patents, scientific publications, and even public use or traditional knowledge. If an invention is found in the prior art, it lacks the necessary novelty for patenting.

286. (A) P-2, Q-1, R-4, S-3
Patents protect inventions and novel processes, while copyright is for literary and artistic works. Trademarks are used for brand names and logos, and Geographical Indications (GI) protect goods

213. (A) Cell wall-degrading enzymes
Polygalacturonase-inhibiting proteins (PGIPs) are engineered into plants to counteract specific cell wall-degrading enzymes, such as polygalacturonases, secreted by necrotrophic fungi. These fungal enzymes break down the pectin in the plant cell wall to facilitate invasion. By inhibiting these enzymes, PGIPs slow down the infection process and help maintain the structural integrity of the plant tissues during a fungal attack.

214. (B) It results in broad-spectrum resistance against entirely unrelated viruses.
While RNAi is a powerful tool for viral resistance by targeting specific viral RNAs for degradation, it generally does not result in broad-spectrum resistance against entirely unrelated viruses. The silencing is highly sequence-specific, meaning that the guide siRNAs produced must be complementary to the target virus. Therefore, a construct designed for one virus typically will not protect against another distantly.

215. (A) I, II and III
Valid strategies for engineering fungal resistance include the overexpression of chitinases and glucanases to degrade cell walls, as well as the expression of genes for phytoalexin biosynthesis to produce antimicrobial compounds. However, expressing viral coat proteins is a strategy specifically for viral resistance, not fungal defense. Thus, combining enzyme-based degradation and chemical-based inhibition provides the most effective approach.

216. (A) Low molecular weight antimicrobial secondary metabolites
Phytoalexins are low molecular weight antimicrobial secondary metabolites that are naturally synthesized by plants in response to pathogen attack. These compounds are highly effective at inhibiting the growth of various fungi and bacteria. By up-regulating the genes involved in their biosynthetic pathways through genetic engineering, researchers can enhance the plant's endogenous chemical defense system, providing increased resistance to diverse diseases.

217. (C) EPSPS enzyme in the shikimate path
The herbicide glyphosate acts by specifically and competitively inhibiting the enzyme 5-enolpyrosylshikimate-3-phosphate synthase (EPSPS) in the shikimate pathway. This enzyme is crucial for the biosynthesis of aromatic amino acids, including phenylalanine, tyrosine, and tryptophan. When EPSPS is blocked, the plant cannot produce these essential proteins, leading to metabolic failure and the eventual death of all treated vegetation.

218. (A) I, II, III and V
Herbicide resistance can be achieved through target site mutations, overproduction of the target enzyme, or metabolic detoxification. The bar gene is a prime example of resistance through detoxification, as it acetylates glufosinate. However, standard EPSPS engineering for glyphosate resistance typically relies on introducing an insensitive version of the enzyme rather than metabolic breakdown of the herbicide itself in the plant.

219. (C) Agrobacterium sp. strain CP4
The CP4 EPSPS gene, used to create Roundup Ready crops, was originally isolated from the Agrobacterium sp. strain CP4. This bacterial version of the enzyme is highly resistant to glyphosate while maintaining its essential catalytic activity. By introducing this gene into crops, researchers developed plants that remain healthy and productive even when sprayed with the herbicide to control surrounding weeds.

220. (D) Ammonia
Glufosinate, also known as phosphinothricin, inhibits the enzyme glutamine synthetase, which is critical for nitrogen metabolism. This inhibition leads to a rapid and toxic accumulation of ammonia within the plant cells. High levels of ammonia destroy cellular structures and interfere with photosynthesis and other vital processes, resulting in the death of the plant within a few days of herbicide application.

221. (C) Acetylation of the herbicide
The bar and pat genes confer resistance to the herbicide glufosinate by encoding the enzyme phosphinothricin acetyltransferase. This enzyme performs a specific chemical modification by adding an acetyl group to the herbicide molecule, rendering it completely non-toxic to the plant. This detoxification mechanism allows transgenic crops to thrive in the presence of glufosinate, providing an effective tool for weed control.

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259. (C) Polyphenol oxidase (PPO)
The 'Arctic Apple' is engineered to resist enzymatic browning by silencing the genes that encode the enzyme polyphenol oxidase (PPO). In conventional apples, PPO reacts with phenolic compounds when the fruit is cut or bruised, creating the brown pigment melanin. By eliminating PPO activity, the sliced apples remain white and fresh-looking for much longer, reducing food waste and improving appeal.

260. (A) P-3, Q-4, R-1, S-2
Delayed softening is achieved by targeting polygalacturonase, while delayed ripening involves ACC synthase. Non-browning traits are created by silencing polyphenol oxidase, and high oleic oil is produced by inhibiting the FAD2 enzyme. These targeted genetic modifications allow for precise improvements in post-harvest quality, providing significant benefits to both producers and consumers in the agricultural supply chain and food industry.

261. (C) Coconut and Palm kernel oil
High laurate canola was developed as a domestic and sustainable alternative source of lauric acid, which is traditionally obtained from tropical oils like coconut and palm kernel oil. Lauric acid is a medium-chain fatty acid widely used in the production of soaps, detergents, and personal care products. By engineering canola to produce this specific fatty acid, manufacturers gain more flexibility.

262. (B) The endogenous target mRNA
In antisense technology, the introduced transgene is designed to produce an RNA molecule that is complementary to the endogenous target messenger RNA (mRNA). When these two RNA strands meet, they form a double-stranded hybrid that cannot be translated into a protein by the ribosome. Additionally, this hybrid is often targeted for degradation by the cell, effectively silencing the gene's function.

263. (D) Allowing vine-ripening for better flavor
The primary advantage of delayed-ripening transgenic tomatoes is that they can be left to vine-ripen for much longer, which significantly improves their flavor and nutritional content. In contrast, conventional tomatoes are often harvested while still green and hard to survive transport, and then artificially ripened with ethylene. The increased firmness of the transgenic fruit allows for better quality and taste.

264. (A) Prevent black spot bruising in tubers
Silencing polyphenol oxidase (PPO) in potatoes is highly beneficial because it prevents black spot bruising, which occurs when tubers are handled during harvest and transport. This unsightly discoloration leads to significant economic losses for farmers and processors, as affected potatoes are often rejected by consumers and the industry. By eliminating PPO, the potatoes remain clear and high-quality throughout processing.

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265. (C) Manage GMO risks to health/environment
In biotechnology, biosafety primarily addresses the assessment and management of potential risks associated with the use of Genetically Modified Organisms (GMOs). This includes evaluating their impact on human and animal health, as well as the potential environmental consequences, such as gene flow to wild relatives. Proper biosafety regulations ensure that transgenic crops are developed and used responsibly.

266. (A) P-1, Q-2, R-3, S-4
The Institutional Biosafety Committee (IBSC) monitors research at the institutional level, while the Review Committee on Genetic Manipulation (RCGM) approves small-scale trials. The Genetic Engineering Appraisal Committee (GEAC) regulates large-scale trials and commercial releases. Finally, the Food Safety and Standards Authority of India (FSSAI) regulates GM foods for human consumption. These bodies form a comprehensive regulatory framework.

267. (D) Genetic Engineering Appraisal Committee (GEAC)
The Genetic Engineering Appraisal Committee (GEAC) is the apex body in India with the statutory authority to approve the commercial release of any transgenic crop. Operating under the Ministry of Environment, Forest and Climate Change, it evaluates all biosafety and environmental data from field trials. No GM crop can be legally cultivated in India without the final approval and recommendation of GEAC.

268. (D) Living Modified Organisms (LMOs)
The Cartagena Protocol on Biosafety is an international agreement designed to ensure the safe handling, transport, and use of Living

231. (C) Osmoprotectants (compatible solutes)
Proline and glycine betaine are classic examples of osmoprotectants, or compatible solutes, that accumulate in plant cells during abiotic stress. These molecules play a critical role in osmotic adjustment, helping the cell retain water and maintain structural integrity. Unlike other solutes, they do not inhibit enzymatic activities even at high concentrations, making them ideal for protecting the cell.

232. (D) Protecting cellular structures and proteins from desiccation damage
Late Embryogenesis Abundant (LEA) proteins function primarily by protecting cellular structures and other proteins from damage during severe desiccation. These proteins are highly hydrophilic and act as molecular chaperones that prevent the aggregation of essential proteins and stabilize membranes as water is lost. Their presence is a key factor in the drought and cold tolerance of many plant species.

233. (A) Drought and cold
The overproduction of trehalose, a non-reducing disaccharide, in transgenic plants significantly enhances their tolerance to drought and cold stress. Trehalose acts as a powerful osmoprotectant and stabilizer of biological membranes and proteins under extreme conditions. By maintaining cellular integrity and preventing damage during dehydration or freezing, trehalose allows plants to recover more effectively from environmental challenges that would normally be lethal.

234. (A) Vacuolar sodium compartmentalization
Transgenic expression of the NHX1 gene improves salinity tolerance by facilitating the compartmentalization of toxic sodium ions into the vacuole. NHX1 encodes a vacuolar Na+/H+ antiporter that uses the proton gradient to pump sodium out of the cytoplasm. By sequestering sodium in the vacuole, the plant avoids ionic toxicity in the cytoplasm while simultaneously using the ions for osmotic adjustment.

235. (C) Plasma membrane Na+/H+ antiporter
In the SOS (Salt Overly Sensitive) pathway, the SOS1 gene encodes a specific plasma membrane Na+/H+ antiporter. This protein is responsible for actively extruding excess sodium ions from the cytoplasm into the extracellular space or the xylem for transport. By maintaining low cytoplasmic sodium levels, SOS1 plays a fundamental role in protecting plant cells from the toxic effects of high salinity.

236. (B) The promoter regions of cold-responsive (COR) genes
Cold stress tolerance is regulated by CBF/DREB transcription factors, which bind to specific cis-acting elements in the promoter regions of cold-responsive (COR) genes. This binding activates the expression of a suite of genes that produce protective proteins and osmolyptes. This coordinated molecular response is essential for the process of cold acclimation, allowing plants to survive and thrive in low temperatures.

237. (A) Glycine betaine
Glycine betaine is a powerful osmolyte synthesized through a two-step pathway involving the enzymes choline monooxygenase (CMO) and betaine aldehyde dehydrogenase (BADH). In this process, choline is first oxidized to betaine aldehyde, which is then further converted into glycine betaine. Engineering this biosynthetic pathway into crops that do not naturally produce it is a common strategy for enhancing abiotic stress.

238. (B) Compatible solutes interfere significantly with normal cellular metabolism.
Compatible solutes are specifically defined by their ability to accumulate to high concentrations without interfering with normal cellular metabolism or enzymatic activities. This characteristic is what makes them "compatible" with the cell's survival. Incorrectly stating that they interfere with metabolism contradicts their fundamental biological role as protective agents during environmental stress, where they help maintain cellular functions under adverse conditions.

239. (A) Scavenge reactive oxygen species
The engineered overproduction of mannitol in plants provides double protection; it acts as an osmoticum and also helps scavenge reactive oxygen species (ROS). During abiotic stress, ROS levels can rise, causing oxidative damage to lipids, proteins, and DNA. Mannitol's ability to neutralize these free radicals, in addition to its role in water retention, makes it a highly valuable tool.

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approach makes it much harder for pests to develop resistance. Pyramiding is a key strategy for ensuring the long-term durability and effectiveness of Bt crops.

204. (D) Secreted during vegetative growth
Vegetative insecticidal proteins (Vip) differ from traditional Cry proteins because they are secreted by Bacillus thuringiensis during its vegetative growth phase, rather than being stored in crystals during sporulation. Vip proteins often target different receptors in the insect gut, making them useful for gene stacking with Cry proteins. This provides a broader spectrum of activity and helps manage the development of resistance.

205. (A) Pathogen-derived resistance
Coat-protein mediated resistance (CPMR) is a classic example of pathogen-derived resistance, where a gene from the pathogen itself is used to confer protection to the host. By expressing the viral coat protein in transgenic plants, the host becomes resistant to the corresponding virus. This innovative concept has been successfully applied to develop resistance against numerous economically important plant viruses worldwide.

206. (D) Viral uncoating
Transgenic expression of viral coat proteins generally prevents infection by interfering with the early step of viral uncoating. When the virus enters a cell already filled with its own coat protein, the high concentration prevents the viral genome from being released. Without the release of its genetic material, the virus cannot initiate transcription or replication, effectively stopping the infection process.

207. (A) Pathogen attack
Pathogenesis-related (PR) proteins are a diverse group of proteins naturally produced by plants as part of their defense response to pathogen attack. These proteins are induced by signaling molecules and accumulate locally and systemically to inhibit the growth and spread of fungi, bacteria, and viruses. Many PR proteins possess direct antimicrobial activities, such as degrading microbial cell walls or membranes.

208. (A) I and II
PR-2 proteins (beta-1,3-glucanases) and PR-3 proteins (chitinases) are essential components of the plant's defense system that directly target and degrade fungal cell walls. Glucanases break down the glucan polymers, while chitinases digest the chitin microfibrils that provide structural integrity to most fungi. By overexpressing these enzymes in transgenic plants, researchers can significantly enhance resistance against a wide range of fungi.

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209. (B) Papaya ringspot virus
The first commercially approved virus-resistant transgenic crop was the papaya, engineered to resist the Papaya Ringspot Virus (PRSV). This achievement saved the Hawaiian papaya industry from near-total collapse caused by the devastating virus. By incorporating the viral coat protein gene into the papaya genome, researchers successfully developed varieties that could thrive even in areas with high disease pressure.

210. (A) Fungi
Chitinases are frequently utilized in transgenic plants to confer resistance against fungal pathogens. Chitin is a primary and essential component of the cell walls of most fungi, providing them with structural strength. By expressing high levels of chitinase enzymes, the plant can actively degrade the fungal cell wall during an attempted infection, leading to the lysis and death of the fungus.

211. (C) Disrupting microbial cell membranes
Defensins are small, cysteine-rich peptides that exert antimicrobial activity primarily by disrupting microbial cell membranes. These positively charged peptides interact with the negatively charged lipids of the fungal or bacterial membrane, creating pores or causing structural instability. This leads to the leakage of cellular contents and rapid cell death, providing a robust and broad-spectrum defense mechanism in transgenic plants.

212. (D) Replicase-mediated resistance
Replicase-mediated resistance is a transgenic strategy that relies on the expression of a defective or modified viral replicase enzyme. This non-functional protein competes with the wild-type viral enzyme for essential host factors or viral RNA, thereby inhibiting the replication of the virus. This approach provides a high level of protection and is a specialized form of pathogen-derived resistance against viruses.

that are normally performed by several different enzymes in plants. By bridging this metabolic gap in the rice endosperm, crtI enables the continuous production of carotenoids, eventually leading to beta-carotene.

250. (C) A is true but R is false.
Biofortification via genetic engineering is a highly sustainable and cost-effective approach to combat micronutrient malnutrition because the nutrients are delivered directly through the staple crops already grown by farmers. However, the reasoning provided is incorrect; biofortification does not require expensive dietary supplements. Instead, it provides a self-sustaining solution where the nutritional benefit is embedded within the seeds themselves.

251. (D) Essential amino acids
The Amaranth seed albumin (AmA1) gene has been expressed in transgenic potatoes to significantly increase their protein content and the levels of essential amino acids, such as lysine and sulfur-containing amino acids. Potato tubers are naturally low in protein, but the incorporation of this high-quality albumin improves their overall nutritional value, offering a better food source for protein-deficient populations worldwide.

252. (B) Anthocyanins
The 'purple tomato' was genetically engineered to accumulate high levels of anthocyanins, which are powerful antioxidant compounds naturally found in fruits like blueberries. By expressing specific transcription factors from snapdragon, researchers activated the entire anthocyanin biosynthetic pathway in the tomato fruit. These modified tomatoes offer enhanced health benefits, including potential anti-inflammatory and anti-cancer properties, due to their significantly increased antioxidant capacity.

253. (C) Delayed ripening and softening
The Flavr Savr tomato was the first genetically modified food to be commercialized and was specifically engineered for delayed ripening and softening. By slowing down the natural degradation of the cell wall, the tomatoes could stay on the vine longer to develop more flavor and had a significantly longer shelf life. This reduced post-harvest losses and improved fruit quality for consumers.

254. (D) Polygalacturonase
Flavr Savr tomatoes utilized antisense technology to inhibit the expression of polygalacturonase (PG), a key cell wall-degrading enzyme. PG is responsible for breaking down pectin, which leads to fruit softening during ripening. By reducing PG activity, the tomatoes remained firm for a longer period, allowing them to be transported more easily without bruising and reducing the need for premature harvesting.

255. (A) ACC synthase
The enzyme 1-aminocyclopropane-1-carboxylate (ACC) synthase is the primary rate-limiting step in the biosynthesis of ethylene, the hormone that triggers fruit ripening. By targeting this enzyme for inhibition through genetic engineering, researchers can effectively control the timing and rate of ripening. This approach allows for the development of fruits with extended shelf life and better quality during transport and storage.

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256. (B) Delayed fruit ripening and extended shelf life
Suppressing the activity of ACC oxidase, the final enzyme in the ethylene biosynthetic pathway, results in delayed fruit ripening and an extended shelf life. By significantly reducing the production of ethylene, the physiological signals that trigger softening and decay are slowed down. This allows the fruit to be stored for longer periods and reach distant markets in better overall condition.

257. (B) Oleic acid
Genetic modification of oil quality often aims to increase the proportion of oleic acid, a monounsaturated fatty acid that provides improved oxidative stability and various health benefits. High-oleic oils are less prone to rancidity and do not require partial hydrogenation, which eliminates the production of harmful trans fats. This makes them highly desirable for both the food industry and consumers.

258. (A) FAD_2 (fatty acid desaturase 2)
To achieve high oleic acid content in transgenic soybeans, RNAi technology is used to silence the FAD_2 (fatty acid desaturase 2) enzyme. FAD_2 is responsible for converting oleic acid into linoleic acid. By blocking this conversion, oleic acid accumulates to much higher levels in the seed oil. This modification significantly improves the oil's thermal stability and its nutritional profile.

222. (D) Aromatic amino acids
The shikimate pathway is a vital metabolic route in plants and microorganisms responsible for the biosynthesis of aromatic amino acids, such as phenylalanine, tyrosine, and tryptophan. These amino acids are essential building blocks for proteins and precursors for many other important compounds, including lignin and various secondary metabolites. Because this pathway is targeted by glyphosate, its disruption is lethal.

223. (C) The shikimate pathway is absent in mammals.
Engineering resistance to glyphosate is considered safe for humans and animals because the shikimate pathway, which the herbicide targets, is entirely absent in mammals. Humans must obtain aromatic amino acids through their diet. This lack of a biological target ensures that glyphosate has very low toxicity to non-plant life, making it a highly effective and selective tool for agricultural use.

224. (D) Acetolactate synthase (ALS)
Sulfonylurea and imidazolinone herbicides function by inhibiting the enzyme acetolactate synthase (ALS), also known as acetohydroxyacid synthase. This enzyme is the first step in the biosynthetic pathway for branched-chain amino acids, such as leucine, isoleucine, and valine. By blocking ALS, these herbicides prevent the production of these essential proteins, leading to the cessation of growth and eventual plant death.

225. (A) I, II, III and IV
Correct gene-herbicide resistance pairs include CP4 EPSPS for glyphosate, bar and pat for glufosinate, and bxn for bromoxynil. These genes provide either an insensitive target enzyme or a detoxification mechanism. However, ALS mutations confer resistance to sulfonylureas or imidazolinones, not paraquat, which has a completely different mode of action. Therefore, pairs I through IV are accurately described.

226. (A) Nitrilase
Bromoxynil resistance is engineered into crops using the bxn gene derived from the bacterium Klebsiella ozaenae. This gene encodes a specialized nitrilase enzyme that detoxifies the herbicide by converting it into the non-toxic compound 3,5-dibromo-4-hydroxybenzoic acid. By expressing this enzyme, transgenic plants can survive the application of bromoxynil, allowing for effective broadleaf weed control in various agricultural systems.

227. (C) The emergence of herbicide-resistant "superweeds"
A primary environmental concern associated with herbicide-tolerant crops is the emergence of "superweeds" that have developed resistance to the same herbicides. Widespread and repeated use of a single herbicide like glyphosate creates intense selection pressure on weed populations. Over time, resistant individuals survive and multiply, eventually rendering the herbicide ineffective and necessitating the use of more toxic alternatives for management.

228. (D) Chloroplast
The introduction of a modified EPSPS gene requires targeting the resulting protein to the chloroplast, as this is the specific subcellular organelle where the shikimate pathway occurs. To achieve this, the transgene is typically fused with a transit peptide sequence that guides the protein across the chloroplast membranes. Proper localization is essential for the enzyme to function correctly and provide resistance.

229. (C) Drought and salinity stress
Osmoprotectants, also known as compatible solutes, are small, highly soluble molecules engineered into plants to alleviate osmotic stress caused by drought and salinity. These molecules, such as proline or glycine betaine, help maintain cellular turgor and protect essential proteins and membranes from desiccation without interfering with normal metabolism. By accumulating these solutes, plants can better survive extreme water-deficit.

230. (A) 2, 1, 3, 4
The plant's response to drought stress begins with the perception of a soil water deficit by the roots. This signal triggers a rapid increase in the concentration of the hormone abscisic acid (ABA). The rising ABA levels then cause the stomata to close, which effectively reduces the transpiration rate to conserve water. This coordinated sequence is vital for survival during stress.

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Modified Organisms (LMOs) resulting from modern biotechnology. It focuses specifically on the cross-border movement of these organisms to prevent adverse effects on biological diversity and human health. The protocol establishes a global framework for risk assessment and informed decision-making.

269. (C) To evaluate the agronomic performance and biosafety under restricted environmental conditions
Confined field trials are conducted for GM crops to evaluate their agronomic performance and biosafety under strictly restricted and monitored environmental conditions. These trials are essential for gathering real-world data on how the transgene behaves in the field, including its impact on non-target organisms and the potential for gene flow. The results are critical for the regulatory approval process for commercialization.

270. (B) A weed
Risk assessment of a transgenic crop includes evaluating its potential to become a weed in the natural environment. Regulators examine whether the added transgene provides a significant fitness advantage, such as herbicide resistance or extreme drought tolerance, that could allow the plant to outcompete native species and disrupt ecosystems. This assessment ensures that the crop does not cause unforeseen ecological harm.

271. (A) Pollen flow to wild relatives or non-GM crops
Gene flow is a major environmental biosafety concern that refers to the unintended transfer of transgenes from a GM crop to wild relatives or non-GM crops through pollen flow. If the transgene integrates into the genome of nearby plants, it could lead to the development of herbicide-resistant weeds or the loss of genetic purity in conventional crops. Managing this is vital.

272. (D) Known established allergens
Allergenicity assessment of a novel transgenic protein involves a detailed comparison of its amino acid sequence with databases of all known established allergens. If a protein shows significant similarity to a known allergen, it may pose a risk of triggering allergic reactions in sensitive individuals. This bioinformatics approach is a critical step in ensuring the food safety of transgenic crops.

273. (B) Ministry of Science and Technology (DBT)
The Review Committee on Genetic Manipulation (RCGM) functions under the Department of Biotechnology (DBT), which is part of the Ministry of Science and Technology in India. The RCGM is responsible for overseeing and approving all research activities involving genetic manipulation, including small-scale laboratory experiments and confined field trials. Its role is essential for maintaining safety and scientific integrity.

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274. (A) That a GM crop is as safe and nutritious as its conventional counterpart
Substantial equivalence is a fundamental concept used in biosafety to establish that a GM crop is as safe and nutritious as its conventional counterpart. This principle involves comparing the molecular, nutritional, and toxicological profiles of the transgenic plant with those of the non-GM variety. If no significant differences are found, the GM crop is considered to be "substantially equivalent."

275. (C) An external nominee from the DBT
An Institutional Biosafety Committee (IBSC) is mandatory for any organization conducting recombinant DNA research in India. To ensure transparency and compliance with national guidelines, the committee must include an external nominee from the Department of Biotechnology (DBT). This representative oversees the institution's safety protocols and provides an independent link between the research organization and the central regulatory authorities in the country.

276. (D) Bt Cotton
Bt Cotton was the first and remains the only transgenic crop to be legally approved for commercial cultivation in India. Approved in 2002, it was designed to protect cotton plants against the devastating bollworm pest. Its adoption led to a significant increase in cotton yields and a reduction in the use of chemical pesticides, transforming the Indian textile and agricultural industry.

240. (A) Identify transporter gene, Clone into expression vector, Transform plant, Evaluate salinity tolerance
Engineering salt tolerance begins with identifying a suitable ion transporter gene, such as NHX1 or SOS1. The gene is then cloned into an appropriate expression vector and used to transform the target plant. Finally, the resulting transgenic lines are evaluated under various salinity levels to confirm improved performance. This logical sequence ensures that the genetic modification translates into a functional phenotype.

241. (B) Vitamin A
Golden Rice was genetically engineered to address Vitamin A deficiency, a major public health problem in many developing countries where rice is a staple food. By introducing the biosynthetic pathway for beta-carotene, a precursor of Vitamin A, into the rice endosperm, researchers created a biofortified crop that can provide this essential nutrient through the diet, potentially preventing childhood blindness.

242. (A) Beta-carotene
The endosperm of wild-type rice naturally lacks beta-carotene, the yellow-orange pigment that the human body converts into Vitamin A. While rice plants produce beta-carotene in their leaves for photosynthesis, the pathway is inactive in the edible grain. Genetic engineering was required to "turn on" this pathway in the endosperm, resulting in the characteristic golden color and the improved nutritional value.

243. (C) Daffodil (Narcissus pseudonarcissus)
The original Golden Rice prototype incorporated the phytoene synthase (psy) gene derived from the daffodil plant (Narcissus pseudonarcissus). This enzyme is the first and most critical step in the carotenoid biosynthetic pathway, converting geranylgeranyl diphosphate into phytoene. While successful in proving the concept, the use of the daffodil gene initially resulted in relatively low levels of beta-carotene in the grain.

244. (D) Erwinia uredovora
To complete the beta-carotene biosynthetic pathway in Golden Rice, the crtI gene was introduced from the bacterium Erwinia uredovora. This bacterial gene encodes a multi-functional phytoene desaturase that can perform all the subsequent steps to convert phytoene into lycopene. Using a single bacterial enzyme was highly efficient, as it replaced the need for multiple separate plant enzymes to achieve carotenoid synthesis.

245. (C) Maize (Zea mays)
Golden Rice 2 achieved significantly higher levels of beta-carotene, up to 23 times more than the original version, by substituting the daffodil psy gene with the psy gene from maize. Researchers found that the maize enzyme was much more active in the rice endosperm. This improved version provides a much more effective source of pro-vitamin A for individuals in need.

246. (B) Ferritin
Iron biofortification in rice often involves the transgenic expression of ferritin, a specialized iron-storage protein found in plants and animals. By overexpressing ferritin specifically in the rice endosperm, researchers can significantly increase the total iron content of the grain. This approach aims to address iron-deficiency anemia, which is particularly prevalent in populations that rely heavily on white rice for nutrition.

247. (D) Chelating essential dietary minerals
Phytic acid in seeds negatively impacts nutritional quality by acting as an anti-nutrient that chelates essential dietary minerals, such as iron, zinc, and calcium. This binding prevents these minerals from being absorbed in the human digestive tract, leading to deficiencies even if the minerals are present in the food. Reducing phytic acid levels is therefore a key goal in biofortification strategies.

248. (A) Phytase
Transgenic approaches to reduce phytic acid often involve expressing the enzyme phytase, which breaks down phytic acid into inorganic phosphate and myo-inositol. By degrading this anti-nutrient, phytase releases bound minerals, making them more bioavailable for human absorption. This technique is particularly valuable for improving the nutritional value of cereal grains and legumes that are naturally high in phytate levels.

249. (A) Phytoene desaturase
In the development of Golden Rice, the crtI gene (phytoene desaturase) was expressed to direct the synthesized precursor phytoene into the lycopene pathway. This bacterial enzyme efficiently catalyzes multiple desaturation steps

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that originate from a specific territory and possess distinct qualities. These various IPR tools are designed to protect different forms of human creativity and ensure fair competition in the global market.

287. (A) Specifically designed for unique subjects
The term 'Sui Generis' in intellectual property refers to a system that is specifically designed "of its own kind" for unique subjects that do not fit into traditional patent or copyright frameworks. For example, many countries have developed sui generis systems for protecting plant varieties or traditional knowledge. This allows for customized rules that balance the needs of various stakeholders effectively.

288. (D) Sovereign rights of nations over their biological resources and equitable benefit sharing
The Convention on Biological Diversity (CBD) emphasizes the fundamental principle that nations have sovereign rights over their own biological resources. It promotes the conservation of biodiversity and the sustainable use of its components. A core goal of the CBD is to ensure the fair and equitable sharing of benefits arising from the utilization of genetic resources, particularly with indigenous communities.

289. (A) Exclusive control over propagating material
Plant Breeders' Rights (PBR) grant the breeder of a new plant variety exclusive control over the propagating material, such as seeds, cuttings, and tissue cultures. This right allows the breeder to prevent others from producing or selling the variety without a license. PBRs are designed to encourage investment in plant breeding by allowing breeders to recover their research and development costs.

290. (A) Both A and R are true and R is the correct explanation of A.
The PPV&FR Act of India is unique globally because it simultaneously protects the rights of breeders, researchers, and farmers. This balance is achieved by granting breeders exclusive rights to their new varieties while explicitly allowing farmers to save, use, and even sell their farm produce, including seeds. This comprehensive approach recognizes the historical and ongoing contribution of farmers to biodiversity.

291. (C) Distinctiveness, Uniformity, and Stability
To be registered under the PPV&FR Act, a new plant variety must fulfill the criteria of DUS, which stands for Distinctiveness, Uniformity, and Stability. Distinctiveness means the variety must be clearly distinguishable from any other known variety. Uniformity requires the plants to be sufficiently similar in their essential characteristics, and stability ensures that these traits remain unchanged through successive generations of propagation.

292. (D) Breeders can freely use a protected variety as an initial source of variation for creating other new varieties.
Under the UPOV Convention, the 'Breeders' Exemption' allows breeders to freely use a protected variety as an initial source of variation for creating other new varieties. This provision ensures that intellectual property rights do not hinder scientific progress or the development of improved crops. By allowing researchers to build upon existing innovations, the exemption promotes continuous advancement in the agricultural sector.

293. (C) 2001
In India, the Protection of Plant Varieties and Farmers' Rights (PPV&FR) Act was enacted in 2001. This legislation was developed as a sui generis system to comply with the TRIPS agreement while also addressing the unique needs of Indian agriculture. It represents a landmark legal framework that acknowledges the rights of both commercial plant breeders and traditional farming communities in the country.

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294. (B) A farmer cannot sell the seed under the brand name of the registered breeder.
Under the PPV&FR Act, a farmer is allowed to save and sell seeds of a protected variety, but they cannot sell the seed under the official brand name of the registered breeder. This restriction protects the breeder's commercial identity and trademark while still ensuring that farmers retain their traditional right to exchange and sell produce within their local communities.

295. (C) Already available in the market or are farmers' varieties
Extant varieties, which can be registered under the PPV&FR Act, include those that are already available in the market or are recognized as farmers' varieties. These are varieties that were

in existence before the act was implemented. By allowing for the registration of extant varieties, the law provides a way to document and protect existing plant genetic resources for future use.

296. (A) Minor genetic changes to a protected variety
The concept of "essentially derived varieties" (EDV) was introduced to protect original breeders from others making only minor genetic changes to a protected variety and claiming it as a new invention. An EDV is a variety that is predominantly derived from an initial variety but retains its essential characteristics. This ensures that the primary breeder receives a fair share of benefits.

297. (A) National Gene Fund
The National Gene Fund is a specific fund constituted under the PPV&FR Act to support the conservation and sustainable use of genetic resources by farming communities. It is funded through benefit-sharing payments, registration fees, and government grants. The money is used to reward farmers for their role in preserving biodiversity and to support local initiatives for the conservation of plant varieties.

298. (A) It strictly prohibits farmers from saving seeds of a registered variety.
It is incorrect to state that the PPV&FR Act prohibits farmers from saving seeds of a registered variety. In fact, one of the most significant and unique features of the Indian Act is the explicit protection of farmers' rights to save, sow, resow, and exchange their seeds. This ensures that traditional agricultural practices and food security for small-scale farmers are maintained.

299. (C) 18 years
Under the PPV&FR Act, the maximum duration of protection granted for trees and vines is 18 years from the date of registration. For other crops, the duration is typically 15 years. This longer period for woody plants reflects the slower growth and longer breeding cycles associated with these species, providing breeders with sufficient time to recover their investments in development.

300. (B) Benefit Sharing
The right of a community to claim compensation for their historical and ongoing contribution to the evolution of a registered plant variety is known as "Benefit Sharing." This principle ensures that the commercial success of a new variety is shared with the people who originally developed or preserved the genetic material. It is a key mechanism for promoting social equity in plant breeding.

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